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## **In-Service Evaluation of the Traffic Alert and Collision Avoidance System (TCAS) Industry Prototype**

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16. Abstract ➔ An operational evaluation of the Traffic Alert and Collision Avoidance System (TCAS II) Industry Prototype was conducted to assess the utility of TCAS II to flight crews, to assess the impacts of TCAS on flight crew workload, to assess the impacts of TCAS on the air traffic control (ATC) system, and to obtain flight crew comments on TCAS design parameters and cockpit displays. The evaluation was conducted on one Boeing 727 aircraft operating in airline revenue service with Piedmont Airlines. Quantitative data on TCAS performance were collected to characterize the location and frequency of TCAS advisories. Qualitative data were collected from flight crews and cockpit observers to assess the utility of TCAS and to assess the impacts of TCAS on ATC and the flight crews. Minor operational anomalies were identified and changes to operational procedures or TCAS logic were recommended. <i>Keywords:</i> <i>Human factors engineering, Avionics, Pilot training</i>			
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# FOREWORD

Under contract DTFA01-80-C-10093, ARINC Research Corporation collected and analyzed data on the operational performance and crew usage of an airborne collision avoidance system developed by the Dalmo Victor Division of Singer. Through a subcontract, Piedmont Airlines installed the collision avoidance system on one of its B-727 aircraft. The system was operated for 828 hours during the ten month evaluation. This report describes the data collected during this evaluation.

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Hundreds of Piedmont people were routinely involved in this project: maintenance and avionics personnel, flight crews, aircraft routing, dispatch, flight training, and flight operations personnel. We wish to especially acknowledge the support provided by the line avionics personnel at Charlotte, Greensboro, and Washington-National airports who assisted in installing and maintaining the avionics; the chief pilots and check airmen who trained the flight crews; the flight crews who operated the TCAS avionics; the flight simulator engineers whose technical expertise was essential in modifying the B-727 simulator; and the personnel in the Airline Operations Control Center who routinely made it easy to get the TCAS observers onto the test aircraft and to keep abreast of the aircraft's routing. Of the many people of Piedmont Airlines, we are especially grateful for the technical and operational expertise provided by Captain Fred Womack, Mr. Kermit Oakley, and Mr. Dave Kepple.

The authors are greatly appreciative of the technical support and guidance provided by Mr. Thomas Williamson of the Federal Aviation Administration's TCAS Program Office.



## SUMMARY

On March 18, 1987, the Traffic Alert and Collision Avoidance System (TCAS) Industry Prototype avionics were operated for the first time in revenue service on board a Piedmont Airlines Boeing 727. This flight was the culmination of years of research, development, and evaluation of TCAS and other collision-avoidance concepts by the aviation community. The TCAS II installation and avionics design for this evaluation were approved by the FAA's Atlanta Aircraft Certification Office (ACO), and the approval to operate the system in revenue service was granted by Piedmont's Principal Operations Inspector (POI). The ACO's approval was in the form of a Supplemental Type Certificate, while the POI's approval was granted through a change to Piedmont's Training Manual and Operations Manual.

In the ten months following the first flight, data were collected on a flight crew's use of the TCAS-displayed information and on the performance of the TCAS avionics during 828 hours of flight time. The data were collected from two sources: (1) a data recording system aboard the test aircraft that recorded quantitative data generated by TCAS each time the system displays were activated; and (2) qualitative comments provided by flight crews and cockpit observers on the utility of TCAS, the impacts of TCAS on a flight crew and Air Traffic Control (ATC), and the performance of TCAS. The data from these two sources were evaluated to satisfy the three major objectives of the Phase II evaluation: (1) assess the impacts of TCAS on flight crews; (2) obtain flight crew opinions on TCAS operational procedures, system design parameters, crew training concept, and system displays; and (3) assess the impacts of TCAS on the ATC system.

The avionics used in this evaluation were developed by the Dalmo Victor Division of Singer and installed in one Boeing 727 operated by Piedmont Airlines. The pilots flying the test aircraft were allowed to respond to advisories issued by TCAS. The test aircraft flew normal routes and operated from a variety of major and small terminal areas. No special handling was provided by ATC for the test aircraft.

During the 828 hours of observed operation, 471 TCAS Cautions and 37 TCAS Warnings were observed. A total of 723 Cautions and 48 Warnings were recorded during this evaluation. The discrepancy between the number

of observed advisories and the number of recorded advisories results either from not allowing untrained crews to operate TCAS or from not having an observer on board a flight. TCAS Cautions averaged one each 1.8 flight hours, and TCAS Warnings averaged one each 22.4 flight hours. The total advisory counts and advisory rates are shown in Table S-1. Forty-eight percent of the TCAS Cautions were issued against non-altitude reporting intruders. Seventy percent of the advisories occurred below 10,000 feet mean sea level (MSL), and 80 percent occurred within 50 nautical miles (nm) of a flight's departure or arrival airport. Seventy-four percent of the advisories (see Figure S-1) were caused by aircraft with a  $\pm 45$  degree relative bearing from the test aircraft when the Cautions and Warnings were issued.

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Table S-1. Advisory Counts and Rates

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<u>Advisory</u>	<u>Count or Rate</u>
TCAS Cautions	
Observed	471
Recorded	723
Non-Mode C	48%
TCAS Caution Frequency	1 per 1.76 flight hours 1 per 1.52 flight segments
TCAS Warnings	
Total	48
Observed	37
TCAS Warning Frequency	1 per 22.4 flight hours 1 per 19.3 flight segments

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Of the 48 Warnings, 39 were corrective advisories that directed a change in the test aircraft's vertical rate and 9 were preventive advisories that instructed a crew to avoid certain deviations from the existing vertical rate. Only five of the corrective advisories were issued while the test aircraft was level at an ATC-assigned altitude and the crew responded to the advisories in two of these cases. In both cases, the deviation from the assigned altitude was 300 feet or less. In the other three encounters, the crew had the intruder aircraft in sight and elected not to follow the TCAS advisory.

Thirty-seven of the TCAS Warnings were witnessed by a TCAS observer, and 30 of these were corrective advisories. The flight crews responded to 15 of them. In the other 15 observed encounters which resulted in a corrective advisory, 13 were not followed because the crew had the

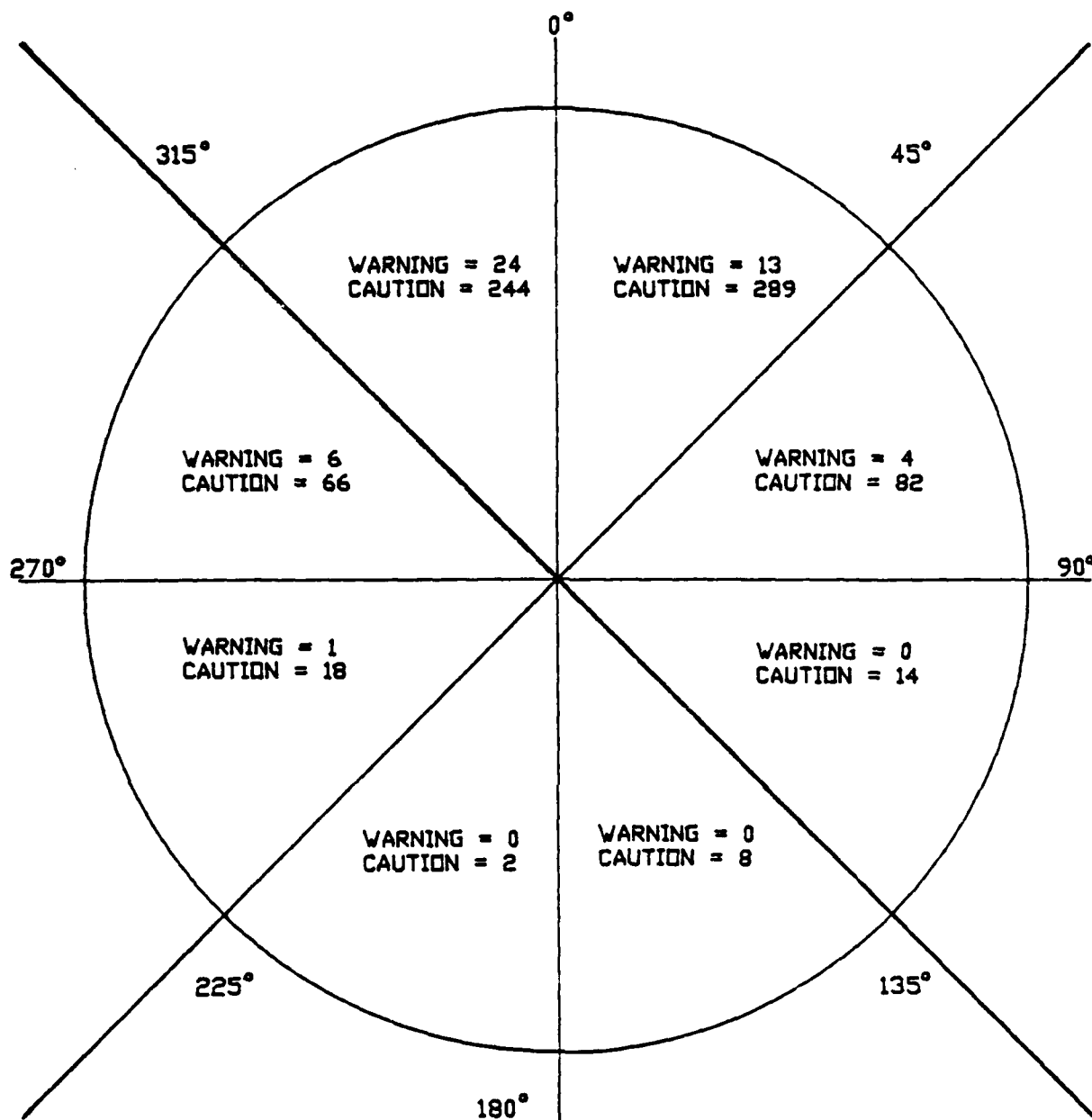


FIGURE S-1

ADVISORIES BY INITIAL BEARING (ALL INTRUDERS)

intruder in sight or had other information from ATC on the intruder and used this information to resolve the situation. In two cases, the intruder was not in sight and the crew was not permitted to respond to the advisory because of an FAA requirement during the first 400 hours of TCAS operation to visually acquire the intruder before following a TCAS advisory.

## RESULTS

The comments received from the observers and flight crews indicate that TCAS is an effective supplement to see-and-avoid and to the separation services provided by ATC. The crews were very positive toward TCAS throughout the evaluation and considered it a valuable addition to the cockpit. They were able to interpret the TCAS displays with minimal problems and demonstrated the ability to integrate TCAS with other cockpit tasks without detracting from the performance of other tasks. The crews had very few comments on the amount and types of information displayed by TCAS. There were mixed feelings among the crews regarding the use of the TCAS/TRACKS display mode to provide a momentary display of nearby aircraft. Some crews considered the 15-second momentary display inadequate and advocated a full-time display, while other crews considered the 15-second display to be satisfactory. All the crews using this display mode believed that the display parameters used in this evaluation ( $\pm 1200$  feet relative altitude and 4 nm) were too restrictive.

A major benefit of TCAS was its ability to assist the crews in visually acquiring nearby traffic. Figure S-2 shows that during the Phase II evaluation, 62 percent of the altitude reporting intruders and 20 percent of the non-altitude reporting intruders causing a TCAS Caution were visually acquired during the encounter.

The quality and quantity of the aural annunciations were generally acceptable to the flight crews, who believed that the aural annunciations were a necessary and essential part of the system. However, the crews thought that the number of aural annunciations should be reduced in a high workload environment such as the one existing during an approach.

The Phase II evaluation has had little or no impact on the ATC system. With a single TCAS-equipped aircraft operating in the system and the small number of advisories requiring a deviation from an assigned altitude, the operation of TCAS was transparent to ATC. While this evaluation had minimal impacts on ATC, additional data are required before a full assessment can be made regarding the use of TCAS in the ATC system.

Several operational and avionics anomalies were identified during the Phase II evaluation. As shown in Figure S-3, nine percent of the Cautions were displayed for less than five seconds. Figure S-4 further indicates that 72 percent of these Cautions were caused by non-altitude

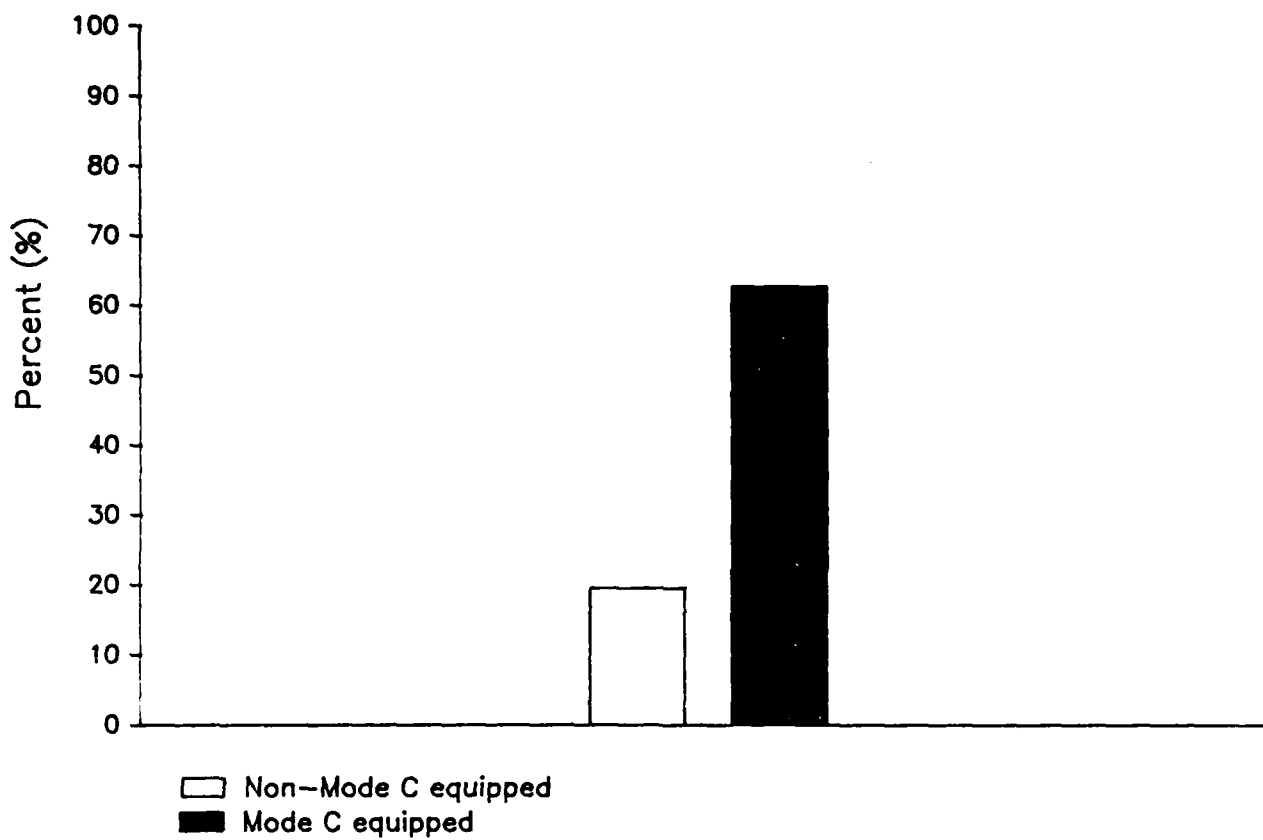


FIGURE S-2  
VISUALLY ACQUIRED TRAFFIC

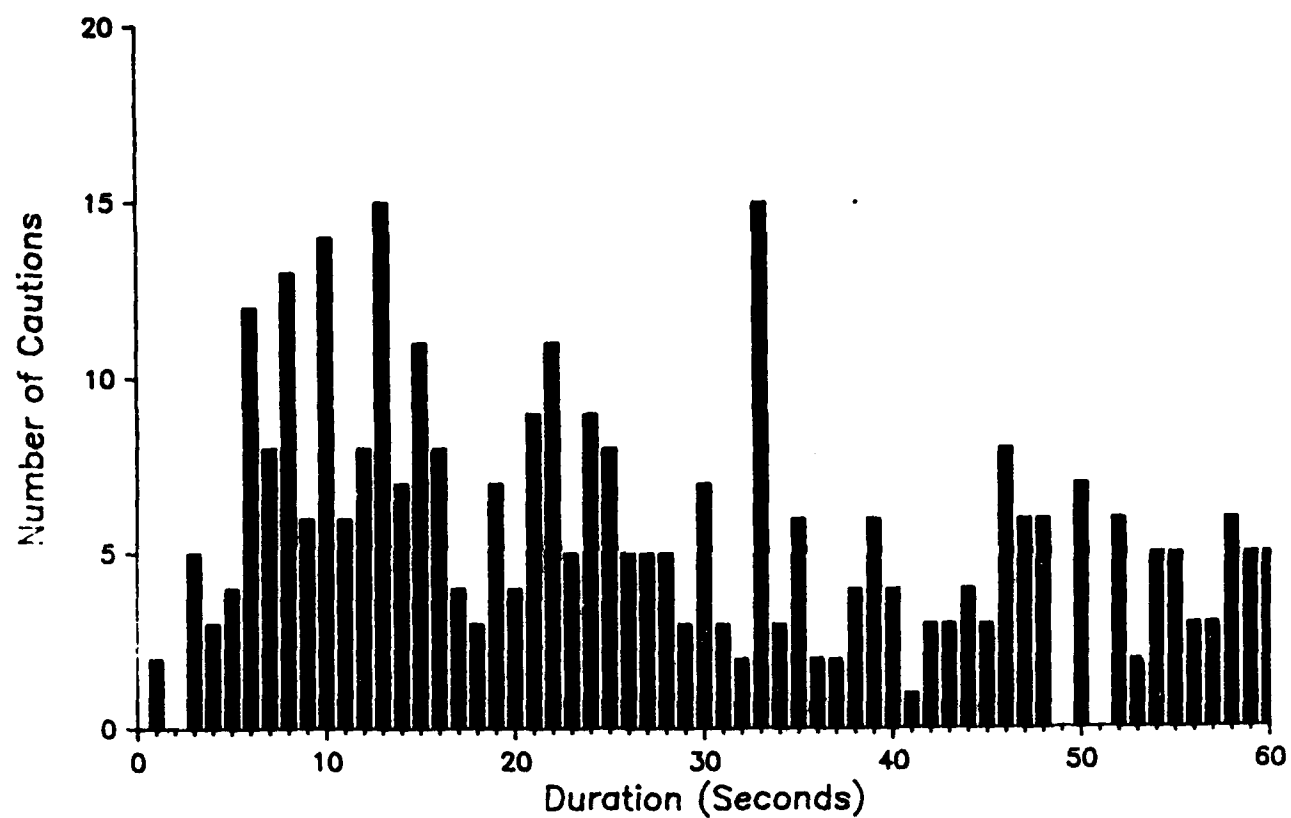


FIGURE S-3

DISTRIBUTION OF TCAS CAUTION DURATION (MODE C INTRUDERS)

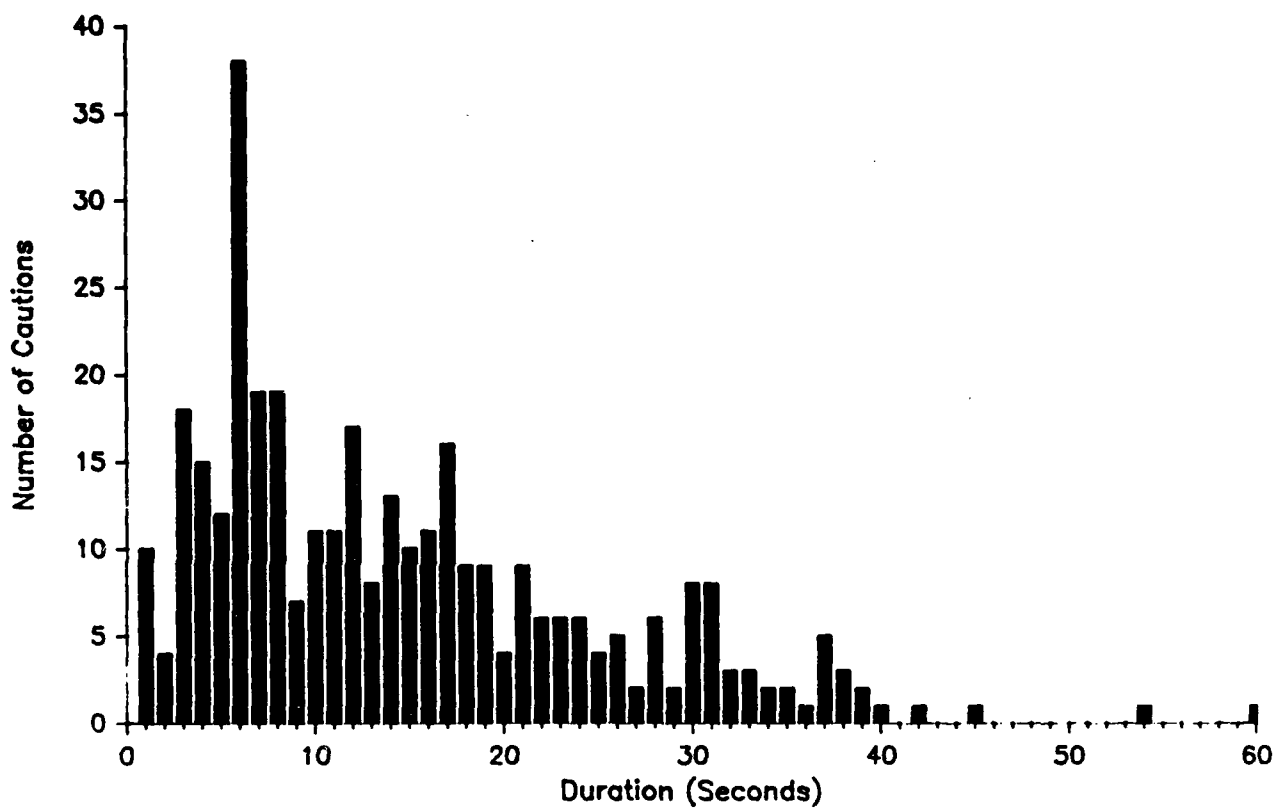


FIGURE S-4  
DISTRIBUTION OF NON-MODE C CAUTION DURATION

reporting intruders. A display of less than five seconds does not provide adequate time for a crew to interpret the displayed data, and these Cautions thus become distractions.

As shown in Figure S-5, non-altitude reporting intruders were also responsible for 70 percent of the TCAS Cautions issued while the test aircraft was below 500 feet above ground level (AGL). Since the cockpit workload is typically high when an aircraft is below 500 feet, these Cautions were a major distraction.

The display of non-altitude reporting intruders with no bearing information available was a source of confusion to the crews. In such cases, a Caution may be issued with information only on the intruder's range.

#### RECOMMENDATIONS

The recommendations listed below should be implemented in avionics used in further TCAS installations. These recommendations should enhance the utility of TCAS and provide the flight crews with additional confidence in the system.

1. Pilots should be provided with the option of selecting either a full-time or momentary display of traffic on the Traffic Advisory display and they should be given the capability to manually set the display parameters for this mode. The pilots should also be provided with a capability to allow traffic to be displayed while their aircraft is on the ground.
2. An additional aural phase should be added to the system's vocabulary to indicate when an advisory is removed.
3. A cockpit ambient noise sensor should be added to control the volume of the TCAS aural system as the cockpit ambient noise level changes.
4. To ensure that all advisories are displayed for at least five seconds, the surveillance algorithms should be modified to ensure that TCAS has a good track on a non-altitude reporting intruder prior to issuing a Caution or the display logic should be modified to provide a five second display of any Caution or Warning traffic displayed by TCAS.
5. The TCAS logic should be modified to inhibit the display of non-altitude reporting intruders while a TCAS-equipped aircraft is below 500 feet AGL.
6. The display of non-altitude reporting intruders without bearing information available should be inhibited. This modification should also eliminate the display of U.S. Navy and Coast Guard ships whose IFFs respond to TCAS interrogations.



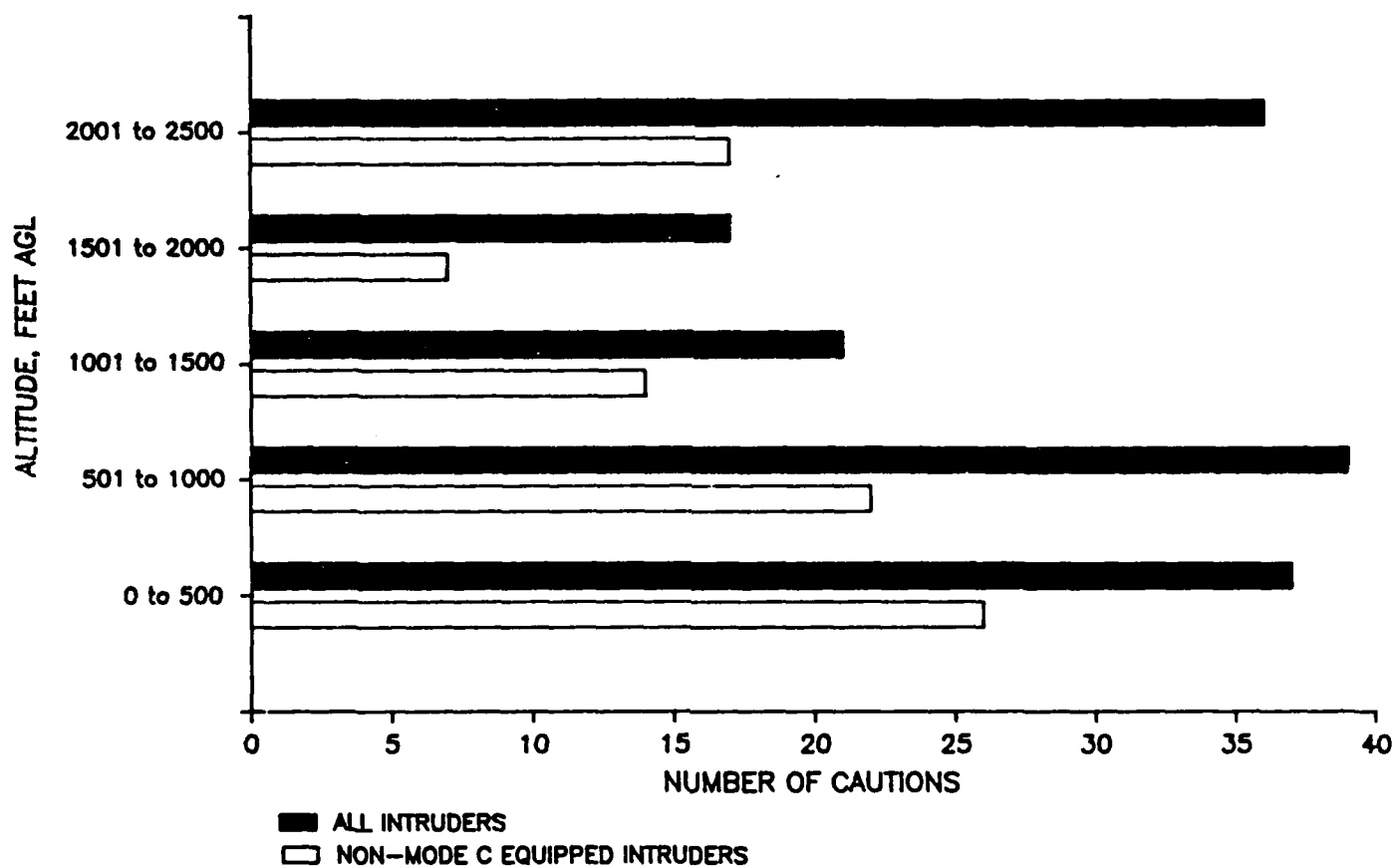


FIGURE S-5

TCAS AIRCRAFT ALTITUDE WHEN CAUTION IS ISSUED

## CONCLUSION

This evaluation has demonstrated that TCAS is useful and that the TCAS-displayed information can be safely used in its intended manner by a flight crew. Additional data are required for a comprehensive assessment of the impacts of TCAS on ATC operations. The anomalies detected during this evaluation are relatively minor, and there are means available for correcting the identified anomalies. The TCAS avionics performed well throughout the evaluation, and no major design deficiencies were identified. The collected data indicate that TCAS is useful; that crews are able to use the system properly without being distracted from other tasks; that TCAS is sufficiently mature to be used in further planned evaluations; and that after correction of the anomalies discussed above, TCAS II will be ready for use by the airlines.

## CONTENTS

	<u>Page</u>
FOREWORD . . . . .	iii
ACKNOWLEDGMENTS. . . . .	v
SUMMARY. . . . .	vii
CHAPTER ONE: INTRODUCTION . . . . .	1-1
1.1 Project Overview. . . . .	1-1
1.2 Objectives. . . . .	1-2
1.3 Scope . . . . .	1-3
1.4 Report Organization . . . . .	1-3
CHAPTER TWO: PRETEST ACTIVITIES . . . . .	2-1
2.1 Evaluation Approach . . . . .	2-1
2.2 Selection of Test Air Carrier . . . . .	2-2
2.3 Selection of Display Contractor . . . . .	2-4
2.4 Development of Test Plan. . . . .	2-5
2.5 Avionics Installation . . . . .	2-5
2.5.1 Test Aircraft. . . . .	2-5
2.5.2 Avionics . . . . .	2-6
2.5.3 System Displays. . . . .	2-7
2.5.4 TCAS Equipment Description . . . . .	2-10
2.5.5 Installation Problems. . . . .	2-14
2.6 Avionics Certification. . . . .	2-15
2.6.1 Certification Requirements . . . . .	2-16
2.6.2 Certification Testing at Dalmo Victor. . . . .	2-17
2.6.3 FAA Technical Center Testing . . . . .	2-19
2.6.4 Certification Testing at Piedmont. . . . .	2-20
2.7 Development of Flight Crew Procedures . . . . .	2-20
2.8 Flight Crew Training Program. . . . .	2-21
2.8.1 Training Approach. . . . .	2-21
2.8.2 Training Program Validation. . . . .	2-24
2.8.3 Training Program Effectiveness . . . . .	2-27
2.9 Observer Program. . . . .	2-28

## CONTENTS (continued)

	<u>Page</u>
CHAPTER THREE: DATA COLLECTION. . . . .	3-1
3.1 Data Collection Methods . . . . .	3-1
3.1.1 Observer Notes . . . . .	3-1
3.1.2 Automatic Data Recording . . . . .	3-2
3.1.3 ATC Data . . . . .	3-3
3.2 Data Collection Problems. . . . .	3-3
3.2.1 Crew Training Requirements . . . . .	3-3
3.2.2 Aircraft Scheduling. . . . .	3-4
3.2.3 Observer Availability. . . . .	3-4
3.2.4 Data Recorder Problems . . . . .	3-4
3.2.5 Time-of-Day Clock. . . . .	3-5
3.2.6 Visual Acquisition Requirement . . . . .	3-6
CHAPTER FOUR: DATA ANALYSIS . . . . .	4-1
4.1 Types of Data . . . . .	4-1
4.2 Quality of Data . . . . .	4-2
4.3 Types of Analysis Performed . . . . .	4-3
4.4 Quantitative Results. . . . .	4-3
4.4.1 Advisory Rates . . . . .	4-4
4.4.2 Types of Intruder Aircraft . . . . .	4-5
4.4.3 Altitude at Time of Advisory . . . . .	4-5
4.4.4 Vertical Separation at Time of Advisory. . . . .	4-8
4.4.5 Range at First Advisory. . . . .	4-11
4.4.6 Vertical Separation at CPA . . . . .	4-11
4.4.7 Range at CPA . . . . .	4-15
4.4.8 Relative Bearing of Threat Aircraft at Time of Advisory . . . . .	4-17
4.4.9 Types of TCAS Warnings . . . . .	4-22
4.4.10 Effect of TCAS Warnings on Flight Path . . . . .	4-22
4.4.11 Duration of Advisories . . . . .	4-24
4.4.12 Geographic Distribution of Advisories. . . . .	4-28
4.4.13 Time-of-Day Analysis . . . . .	4-28
4.5 Qualitative Results . . . . .	4-30
4.5.1 General Assessment . . . . .	4-31
4.5.2 Installation-Specific Comments . . . . .	4-31
4.5.3 Visual Acquisition . . . . .	4-33
4.5.4 TCAS/TRACKS Mode Usage . . . . .	4-34
4.5.5 Pop-Up Warnings. . . . .	4-36

## CONTENTS (continued)

	<u>Page</u>
4.5.6 TCAS Impacts on ATC. . . . .	4-37
4.5.7 Use of TCAS Caution Information. . . . .	4-37
4.5.8 Human Factors Issues . . . . .	4-38
4.5.9 Understanding of TCAS Operation. . . . .	4-40
4.5.10 Impacts of TCAS on Pilot Workload. . . . .	4-40
4.5.11 TCAS Design Parameters . . . . .	4-42
4.5.12 Nuisance Advisories. . . . .	4-42
 CHAPTER FIVE: CONFLICT CASES OF PARTICULAR INTEREST . . . . .	 5-1
5.1 TCAS Warning 6 . . . . .	5-2
5.2 TCAS Warning 10 . . . . .	5-3
5.3 TCAS Warning 11 . . . . .	5-6
5.4 TCAS Warning 12 . . . . .	5-8
5.5 Pop-Up Encounters . . . . .	5-8
5.6 Parallel Runway Warnings. . . . .	5-12
 CHAPTER SIX: AVIONICS AND OPERATIONAL ANOMALIES . . . . .	 6-1
6.1 Interrogation of Ships. . . . .	6-1
6.2 Short Duration Cautions . . . . .	6-2
6.3 Display of Cautions at Low Altitude . . . . .	6-4
6.4 Warnings Issued at CPA. . . . .	6-7
6.5 Volume of Aural Alarm . . . . .	6-9
 CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS. . . . .	 7-1
7.1 Impacts on Crew Workload. . . . .	7-1
7.2 Impacts on ATC. . . . .	7-2
7.3 Effectiveness of Training Program . . . . .	7-2
7.4 Display Interpretation. . . . .	7-3
7.5 Advisory Rates. . . . .	7-3
7.6 Avionics Performance. . . . .	7-4
7.7 Visual Acquisition. . . . .	7-4
7.8 Use of TCAS/TRACKS Mode . . . . .	7-4
7.9 Aural Annunciations . . . . .	7-5
7.10 Short Duration Cautions . . . . .	7-5
7.11 Low Altitude Display of Traffic . . . . .	7-6
7.12 Interrogation of Ships. . . . .	7-6
7.13 Installation Concerns . . . . .	7-7

## CONTENTS (continued)

	<u>Page</u>
APPENDIX A: FLIGHT CREW TRAINING MATERIAL . . . . .	A-1
A.1 Operations Manual Supplement. . . . .	A-3
A.2 TCAS Training Video Script. . . . .	A-17
A.3 Training Syllabus and Quiz. . . . .	A-27
APPENDIX B: OBSERVER TRAINING PROGRAM MATERIAL AND INSTRUCTIONS TO OBSERVERS . . . . .	B-1
B.1 TCAS Observer Training. . . . .	B-3
B.2 Instructions to Observers . . . . .	B-11
B.3 Observer Bulletins. . . . .	B-17
APPENDIX C: TCAS OBSERVER FORMS . . . . .	C-1
APPENDIX D: TCAS WARNING SUMMARY. . . . .	D-1
APPENDIX E: EQUIPMENT MAINTENANCE ACTIVITIES. . . . .	E-1
APPENDIX F: REFERENCES. . . . .	F-1

## CHAPTER ONE

### INTRODUCTION

#### 1.1 PROJECT OVERVIEW

The Federal Aviation Administration (FAA) is developing the Traffic Alert and Collision Avoidance System (TCAS) to help reduce the risk of mid-air collisions. The TCAS program included the development of detection and resolution algorithms, development and testing of flight hardware, development and validation of flight crew procedures, development of flight crew training procedures, and flight testing of TCAS avionics. This report presents the results of an evaluation of a TCAS II prototype installed aboard a commercial airline aircraft operating in revenue service with the crews following advisories issued by TCAS.

The quantitative evaluation of TCAS performance discussed in this report is based on digital data recorded aboard the TCAS aircraft and on written reports from cockpit observers. The reports from the cockpit observers also provide qualitative data on the crews' use of the system and the impact of TCAS operation on ATC. During the initial weeks of the evaluation, several anomalies were detected in the operation of the digital data recorder. These problems, which resulted in the loss of data for several TCAS encounters, were resolved by clarifying the instructions for properly loading data tapes and configuring the data recorder.

The primary purpose of the evaluation was to assess the operational impacts of TCAS on both the flight crew and the Air Traffic Control (ATC) system. A detailed investigation of the technical performance of the system was therefore beyond the scope of this project. The data collected during the evaluation have been furnished to The MITRE Corporation, the FAA Technical Center, and Massachusetts Institute of Technology Lincoln Laboratory for detailed analyses of the technical performance of TCAS. Collectively, this report and the additional technical performance analyses should provide a reliable indication of the TCAS performance in its intended operational environment.

ARINC Research Corporation developed the test concept, prepared the test plan, coordinated the preparation of data needed for the Supplemental Type Certificate (STC), developed changes to Piedmont's Operations Manual, developed a flight crew training program, recruited and trained observers, managed the data collection effort, analyzed the

collected data, provided for system maintenance, and prepared this report. Piedmont Airlines, working as a subcontractor, developed the equipment installation design, installed the equipment, and trained and provided the flight crews who operated the system.

A Boeing 727 aircraft, owned and operated by Piedmont Airlines, was equipped with a set of TCAS avionics, test instrumentation, and data recording equipment manufactured under FAA contract by the Dalmo Victor Division of Singer. The installation also included two modified Instantaneous Vertical Speed Indicators (IVSI) supplied by Teledyne Avionics, and a modified Bendix PPI-1U radar indicator supplied by Dalmo Victor under contract to ARINC Research Corporation. The aircraft installation was designed by Piedmont Airlines, and the aircraft was modified at Piedmont's maintenance facility in Greensboro, North Carolina. An STC for the avionics and aircraft installation was issued by the FAA's Atlanta Aircraft Certification Office (ACO), and operational approval was issued by Piedmont's Principal Operations Inspector (POI).

The TCAS aircraft did not receive special handling by the ATC system and was not assigned special transponder codes, aircraft-type suffixes, flight numbers, or call signs. During the first four months of the evaluation, Piedmont was required to include the comment "TCAS EQUIPPED" in the Remarks section of each flight plan for the TCAS aircraft. However, conversations with controllers indicated that this information was not always included on the flight progress strips, especially in the en route environment and at the arrival airport. On the basis of the results of the first four months of the evaluation, the FAA decided that the annotation was no longer required. In addition to this comment on the flight plan, each ATC facility was notified, via an FAA Notice, that the Phase II evaluation would be taking place. The Notice defined internal FAA procedures for handling any problems caused by TCAS operations and the procedures that would be used by the pilots. The controllers were instructed not to provide any special handling of the TCAS aircraft, and the data indicate that there was no special handling.

Two types of data were recorded during the evaluation. Digital data were automatically recorded each time a potential conflict was detected by TCAS. These data included information on the configuration of the TCAS aircraft, on each intruder aircraft being tracked by TCAS, and on the horizontal and vertical relationship between the TCAS aircraft and each intruder aircraft. Cockpit observers also provided data using a questionnaire. The completed questionnaire provided objective information on a crew's response to TCAS advisories, the effectiveness of TCAS-displayed information, and the impact of TCAS on the flight crews and ATC.

## 1.2 OBJECTIVES

The primary objectives of this operational flight evaluation were to assess the impacts of TCAS operation on flight crew workload; evaluate the impacts of TCAS on the ATC system and individual controllers; and obtain flight crew comments on the system's design parameters, displays, and operational procedures.



The evaluation was also designed to provide additional data on the frequency of TCAS alerts and the circumstances under which TCAS alerts occur, evaluate the effectiveness of the detection and resolution algorithms, evaluate the effectiveness of the flight crew training program, and identify and resolve equipment certification issues.

### 1.3 SCOPE

This report presents the results obtained during the ten month TCAS Phase II Operational Evaluation. The period covered by this report begins on March 18, 1987, and continues through the last flight of the TCAS aircraft on January 29, 1988. During this period, TCAS was operated for a total of 828 hours on 714 flight segments by a large number of flight crews.

### 1.4 REPORT ORGANIZATION

This report is organized into seven chapters and six appendixes. Chapter Two describes the pretest activities completed to obtain the FAA's approval to operate TCAS in revenue service. Chapter Three describes the data collection methods used in the evaluation. Chapter Four presents the results of the data analyses. Chapter Five provides the details of TCAS Warnings that are of special interest to one or more evaluation participants. Chapter Six addresses system and operational anomalies identified during the evaluation. Chapter Seven presents the conclusions drawn from the analyses, together with recommendations for modifications to the TCAS II hardware and algorithms.

The following appendixes are included in this report:

- Appendix A - Flight Crew Training Material
- Appendix B - Observer Training Program Material and Instructions to Observer
- Appendix C - TCAS Observer Forms
- Appendix D - TCAS Warning Summary
- Appendix E - Equipment Maintenance Activities
- Appendix F - References

## CHAPTER TWO

### PRETEST ACTIVITIES

This chapter describes the activities completed before the operational evaluation began. These activities concentrated on planning, defining, and formalizing the relationship of the test participants; designing, fabricating, and testing the installation hardware; certificating the avionics; developing and implementing a flight crew training program; and developing and implementing an observer training program.

#### 2.1 EVALUATION APPROACH

This project was initiated in March 1983 under Contract DTFA01-80-C-10093 between the FAA and ARINC Research Corporation. The contract required collection and analysis of data on the pilot-in-the-loop operation of TCAS aboard an air carrier aircraft flying normal, scheduled routes. The TCAS avionics, the test instrumentation, and the IVSIs were provided to ARINC Research Corporation as Government-Furnished Equipment (GFE). A modification to the TCAS aircraft's weather radar indicator to permit the display of TCAS information was performed by the Dalmo Victor Division of Singer under contract to ARINC Research. The TCAS avionics and test instrumentation were manufactured by Dalmo Victor. The system was subjected to extensive hardware and software testing by Dalmo Victor and then to laboratory and flight tests at the FAA Technical Center to support the FAA's TCAS development efforts. One set of avionics with limited spares was available for this evaluation.

Upon delivery of the TCAS avionics and test instrumentation, the system was installed in a Boeing 727 aircraft owned and operated by Piedmont Airlines. The contract called for the avionics to be flown for a period of eight months, or approximately 2,000 hours. During the evaluation, a group of volunteer observers skilled in jet transport operations flew aboard the TCAS aircraft as cockpit observers to provide a subjective evaluation of the crew's use of TCAS, the impact of TCAS on the flight crew, and the impacts of TCAS on the ATC system.

During the data collection period, data were also electronically recorded. The recordings provide detailed information on the performance of the TCAS avionics and algorithms. The electronically recorded data were correlated with the cockpit observer data to develop a picture of the performance and utility of TCAS.

The pretest activities are explained in greater detail in the following sections.

## 2.2 SELECTION OF TEST AIR CARRIER

The criteria established for selecting the air carrier to be used in this operational evaluation were as follows:

- Operates Boeing 727 aircraft
- Has a mix of short- and medium-range flight segments
- Permits frequent access to the TCAS aircraft
- Permits observers on the flight deck
- Shows a willingness to support the evaluation
- Operates its own engineering and maintenance organizations

Piedmont Airlines met all of these criteria.

The Phase I evaluation of the TCAS avionics was successfully conducted in 1981 and 1982. Piedmont's participation in the Phase I evaluation was a major factor in its selection as the air carrier for Phase II. Piedmont Airlines also volunteered to provide the aircraft for the evaluation.

The requirement for a Boeing 727 aircraft was predicated on the widespread use of this type of aircraft and the availability of an FAA B-727 to support the flight test program at the FAA Technical Center. The B-727 also provides adequate space for two cockpit observers and normally operates on a mix of short- and medium-range flights.

Piedmont's B-727 route structure provides an excellent mix of short- and medium-range operations. It also provides a mix of operations at major terminal areas such as New York, Washington, and Boston and at smaller terminal areas with less traffic such as Greer, South Carolina; Fayetteville, North Carolina; and Grand Rapids, Michigan. In addition, the diversity of the Piedmont B-727 route structure permits an assessment of TCAS performance and utility in airspace with various mixes of air carrier and general aviation traffic. The 727 routings used during this evaluation are shown in Figure 2-1.

The requirement for frequent access to the TCAS aircraft further directed the selection toward Piedmont. Piedmont has major hubs and avionics shops located at Charlotte, North Carolina, and Baltimore, Maryland, which facilitates the changing of data tape cartridges. In addition to these hubs, Piedmont's B-727s routinely operate to and from Washington-National Airport, whose proximity to ARINC Research further facilitated the changing of the data tapes. The tape recorder used in the evaluation required that the tape cartridges be changed every two or three days.



FIGURE 2-1

ROUTES FLOWN BY TEST AIRCRAFT DURING THE PHASE II EVALUATION

An additional consideration was the size of Piedmont's B-727 fleet. The efforts required to coordinate the data collection, aircraft tracking, and observer scheduling would have been unmanageable if the selected air carrier operated a large fleet of B-727s. Piedmont's fleet of 34 B-727s presented relatively few problems, which were overcome with the assistance of Piedmont's Aircraft Scheduling Department.

Access to air carrier cockpits is controlled by both the individual air carrier and the FAA. The FAA will authorize access to the cockpit whenever the person so authorized has valid business and the authorization is requested by the air carrier. Each air carrier has its own policy governing access to the cockpit, and requests are evaluated individually. Because this program required a number of technicians and flight observers to spend considerable time in the cockpit of the TCAS aircraft, the selected air carrier had to permit access to such personnel. The Piedmont Airlines Flight Operations department and the FAA's Carolina Flight Standards District Office were very cooperative in granting the necessary authorizations.

This attitude toward the test observers was one aspect of the positive corporate posture sought for the test. The cooperation exhibited by the Flight Operations Department, Engineering Department, and Avionics Division at Piedmont Airlines assured prompt attention to and correction of any problems.

The in-house engineering and maintenance capability of Piedmont Airlines proved to be the critical factor in meeting the milestones for the design, installation, and certification of the modification to the TCAS aircraft. This integrated engineering and maintenance organization permitted advance selection of the airframe to be modified and assured that the modification would be completed on time during a scheduled maintenance activity.

## 2.3 SELECTION OF DISPLAY CONTRACTOR

The contract between ARINC Research Corporation and the FAA required ARINC Research to ensure that the preliminary display concepts developed by the FAA were compatible with Piedmont's cockpit design and flight crew procedures. After satisfying this requirement, ARINC Research was directed to procure a cathode ray tube (CRT) display for use in displaying traffic advisory information generated by TCAS. The display was procured via a competitive process.

The procurement required the selected contractor to develop a TCAS display system that included a Bendix PPI-1U color weather radar display used by Piedmont Airlines and to provide installation and maintenance support for installing and certifying the display in both Piedmont's and the FAA's B-727s. The display requirements were defined by an FAA memorandum, "System Description for Piedmont Phase II Operational Evaluation," dated September 14, 1982.

The Dalmo Victor Division of Singer was selected as the display contractor. Its design added a single circuit board to the PPI-1U CRT that allowed the CRT to display the TCAS traffic advisory information. The circuit board provided an interface between the CRT and a symbol generator manufactured by The Sperry Corporation under contract to Dalmo Victor. Dalmo Victor was selected because of its technical design and its participation in other phases of the TCAS program.

## 2.4 DEVELOPMENT OF TEST PLAN

A detailed test plan was written by ARINC Research Corporation to serve as a guide for completing this project. The test plan set forth the objectives and scope of the project, defined the test concept, identified the preliminary areas of investigation, discussed the test area and environment, described the data collection and analysis procedures, and outlined the roles of the test participants. The test plan also described the FAA's certification requirements, the proposed flight crew training concept, the aircraft installation configuration, and the limitations and guidelines for conducting the operational evaluation.

The test plan was published in July 1983 as ARINC Research Publication 3011-01-1-3066.

## 2.5 AVIONICS INSTALLATION

The prototype avionics and the recording equipment used in this evaluation were manufactured for the FAA by Dalmo Victor and provided to ARINC Research as GFE. The physical and performance characteristics of this equipment are contained in Reference 5. Although the avionics were a prototype, the equipment was packaged in accordance with normal airline practices. The avionics and the recording equipment were initially installed in the FAA's B-727, which was used to conduct engineering flight tests to verify that the equipment met the FAA's technical and operational requirements. During these flight tests, the equipment was mounted in special racks, secured to cargo pallets in the main cabin of the aircraft. After completion of this testing at the FAA Technical Center, the TCAS avionics and the recording equipment were installed in a Piedmont Airlines B-727.

The aircraft supplied by Piedmont was one of the two aircraft used in the Phase I evaluation completed in 1982. The use of this aircraft, which had been modified to accept the Active Beacon Collision Avoidance System (BCAS) avionics, eliminated the need to perform several steps required in the normal TCAS installation. The installation of the TCAS equipment in the Piedmont aircraft is discussed in the following sections.

### 2.5.1 TCAS Aircraft

The aircraft selected for this evaluation was a Boeing 727-200 series aircraft, registration number N857N. It provided sufficient space in the avionics compartment for the TCAS avionics and data recording

equipment and sufficient space in the top section of the aircraft for mounting the directional antenna. The cockpit of the TCAS aircraft has two forward-facing observer seats, permitting the presence of two TCAS observers or one TCAS observer and a check pilot conducting normal pilot or flight engineer check rides.

### 2.5.2 Avionics

The TCAS avionics and test equipment consisted of the items shown in Table 2-1.

The directional antenna is mounted on the top of the aircraft and the omnidirectional antenna is mounted on the bottom of the aircraft. Both antennas are mounted on the approximate centerline of the fuselage surfaces. The remainder of the avionics and the recording equipment are located in the avionics, or electronics and equipment (E&E), bay.

Table 2-1. TCAS Avionics and Recording Equipment

Unit	Size (Inches)	Weight (Pounds)	Number
Computer Unit	7.5 x 1.1 x 12.5	34.00	1
RF Electronics Unit	10.0 x 7.7 x 12.5	30.00	1
Symbol Generator	2.25 x 7.7 x 12.5	4.00	1
Directional Antenna	8.0 (Dia) x 5.0	5.25	1
Omnidirectional Antenna	5.0 x 1.75 x 2.2	0.25	1
Control/Display Unit	6.3 x 8.1 x 14.0	17.01	1
Cockpit Control Panel	5.8 x 2.0 x 3.25	2.75	1
Recorder	8.0 x 9.7 x 14.5	30.10	1

The TCAS avionics require inputs from other aircraft systems to ensure proper operation. Mode C inputs are taken from the TCAS aircraft's Air Data Computer to enable TCAS to track the altitude of the TCAS aircraft and set internal performance levels. The radar altitude is used to set internal performance levels at low altitude and to inhibit or enable advisories and displays. The position of the flaps and landing gear is provided from the Landing Gear Accessory Unit, as is the air/ground discrete. AC and DC power are taken from the aircraft's radio buses. TCAS also receives an input from and provides an output to the mutual suppression bus to ensure that no more than one type of pulse equipment is transmitting at any given time.

The avionics and aircraft interfaces are diagramed in Figure 2-2.

### 2.5.3 System Displays

The TCAS Cautions and Warnings generated by TCAS are issued to the crew by means of two cockpit displays. Both displays are modifications to existing aircraft instruments or displays. The modified weather radar indicator is shown in Figure 2-3.

TCAS Caution and Warning information is displayed to the flight crew on a modified weather radar indicator, which shows the approximate bearing and range between the TCAS and intruder aircraft. If the intruder is equipped with a Mode C transponder, the intruder's relative altitude is also shown. The information shown during TCAS encounters is displayed as follows:

- Own Aircraft - The location of the TCAS aircraft is represented by a blue chevron located below center on the screen and pointing heading up.
- Range Ring - The own-aircraft symbol is encircled by 12 asterisks, at clock positions 1 through 12. These asterisks correspond to a range of 2 nautical miles from own-aircraft position and can be used to assist the visual search for conflicting traffic.
- Intruder Aircraft - Intruder aircraft are represented by color-coded triangles. Intruders whose range exceeds that of the radar CRT are displayed as a square at the edge of the CRT at the measured bearing. Color coding of displayed information is as follows:
  - Amber - TCAS Caution information. The traffic represents a possible threat. The display helps the crew in visually locating the traffic.
  - Red - TCAS Warning information. The traffic represents an actual threat. An IVSI-displayed warning will be present for all aircraft displayed in red on the CRT.
  - Blue - Proximate Traffic information. The traffic represents transponder-equipped aircraft that are within 4 miles and  $\pm 1,200$  feet. This display represents a minimal-threat or nonthreat aircraft. It assists the crew in visually acquiring nearby traffic.
- Intruder Relative Altitude - This information is displayed as a signed two-digit number representing hundreds of feet. This display altitude is the intruder's altitude relative to the TCAS aircraft--plus (+) for an aircraft above and minus (-) for an aircraft below. For example, +05 indicates that the intruder aircraft is 500 feet above the TCAS aircraft.





TCAS caution:  
Bearing unknown, 1500 ft above,  
4 miles range

TCAS caution:  
1 o'clock, same altitude, level.

TCAS caution:  
10 o'clock, 1000 ft below, climbing

Aircraft causing a  
TCAS warning:  
2 o'clock, 500 ft below, level

TCAS caution:  
3 o'clock beyond range of CRT,  
800 ft above, level.

Your aircraft

Proximate Traffic  
8 o'clock, 1000 ft above, descending

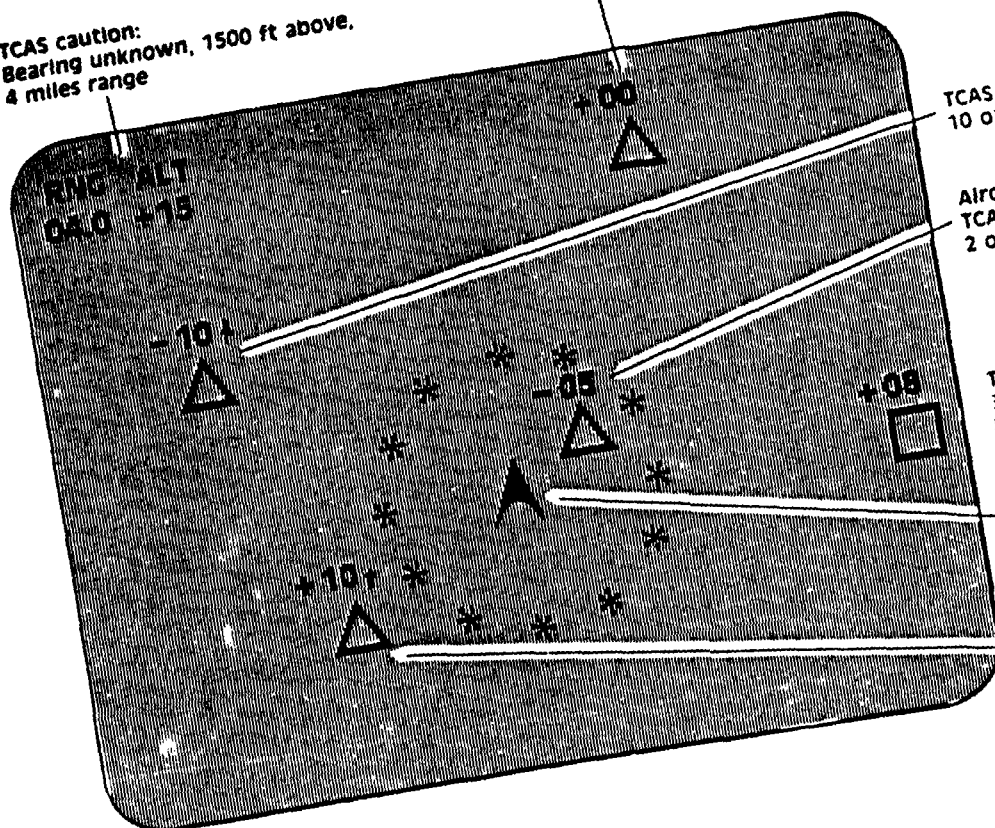


FIGURE 2-3  
MODIFIED WEATHER RADAR INDICATOR

Whenever the intruder is detected to be changing altitude at a rate of at least 500 feet per minute, an arrow appears to the right of the altitude information to indicate a climb or descent.

Non-altitude reporting aircraft are displayed with two question marks (??) over the intruder symbol.

- No-Bearing Targets - Occasionally TCAS may not be able to compute bearing information on an intruder for a short period of time. These aircraft are displayed in a table in the upper left corner of the radar CRT. This table shows the intruder's range and its relative altitude and vertical speed if it is equipped with an altitude reporting transponder.

In addition to the display on the weather radar, the vertical guidance for a TCAS Warning is displayed on a modified IVSI. Both the captain's and the first officer's IVSIs have been modified to include a green climb arrow, a green descend arrow, and a series of segment lights located just inside the indices of the rate-of-climb scale. The segment lights, amber in color, are used to advise the crew to limit the aircraft's vertical speed to 500, 1000, or 2000 feet per minute. An amber fail light is also included on the IVSI face to annunciate system failures detected by the TCAS performance-monitoring software.

The CRT and IVSI displays are supplemented by two Caution/Warning lights mounted underneath the glareshield. Each light has an amber segment, which is illuminated during a TCAS Caution or Traffic Advisory; and a red segment, which is illuminated during a TCAS Warning or Resolution Advisory. The lights remain illuminated until the advisory is cleared or the pilot extinguishes them by depressing either light.

The Caution/Warning lights are intended to alert the crew to the presence of a TCAS Caution or Warning. This visual cue is reinforced by an aural warning system, which uses a C-tone followed by the spoken word "TRAFFIC" to annunciate a TCAS Caution. A TCAS Warning is annunciated by a European siren, followed by the word(s) "CLIMB," "DESCEND," "LIMIT VERTICAL RATE," or "TCAS INVALID." The aural commands for a TCAS Warning are annunciated until the encounter is ended or the commands are silenced by depressing either Caution/Warning light. The indications for each type of TCAS Warning are summarized in Table 2-2.

The locations of all TCAS displays and the TCAS Control Panel (see Section 2.5.4.6) are shown in Figure 2-4.

#### 2.5.4 TCAS Equipment Description

##### 2.5.4.1 Computer Unit

The TCAS computer unit contains six circuit cards and a power supply and includes two processors and associated memory. One processor is used primarily for the surveillance software, while the second is used primarily for the collision-avoidance (CAS) software. In addition to the processors, the computer unit contains the degarblers and video processing hardware; the angle-of-arrival and timing hardware used

Table 2-2. Summary of TCAS Warning Display Indications

Advisory	Indications
CLIMB	European Siren, aural "CLIMB," red Caution/Warning light, green climb arrow on IVSI, and intruder display in red on CRT.
DESCEND	European siren, aural "DESCEND", red Caution/Warning light, green descend arrow on IVSI, and intruder display in red on CRT.
LIMIT VERTICAL RATE	European siren, aural "LIMIT VERTICAL RATE," red Caution/Warning light, lighted amber IVSI segments, and intruder display in red on CRT.
TCAS INVALID	European siren, aural "TCAS INVALID," red Caution/Warning light, flashing green climb and descend arrows on IVSI, and intruder display in red on CRT.
WARNING DISCONTINUED	Climb arrow, descend arrow, or IVSI segment lights extinguished; Caution/Warning lights extinguished; and aural discontinued.

to transfer data and range information from the degarblers to the processors; the transmitter control, signal generator, and self-test control; and the aircraft interface hardware. The unit also contains the capability to process Mode S replies, but this hardware was not used in the Phase II evaluation.

#### 2.5.4.2 RF Electronics Unit

The RF electronics unit, or Bearing Electronics Unit (BEU), contains four receivers, the transmitter, the whisper-shout attenuator, and all required power supplies. The RF unit also serves as the single TCAS interface with the aircraft wiring. All aircraft signals (see Section 2.5.2) are routed through the RF unit to the aircraft interface hardware in the computer unit.

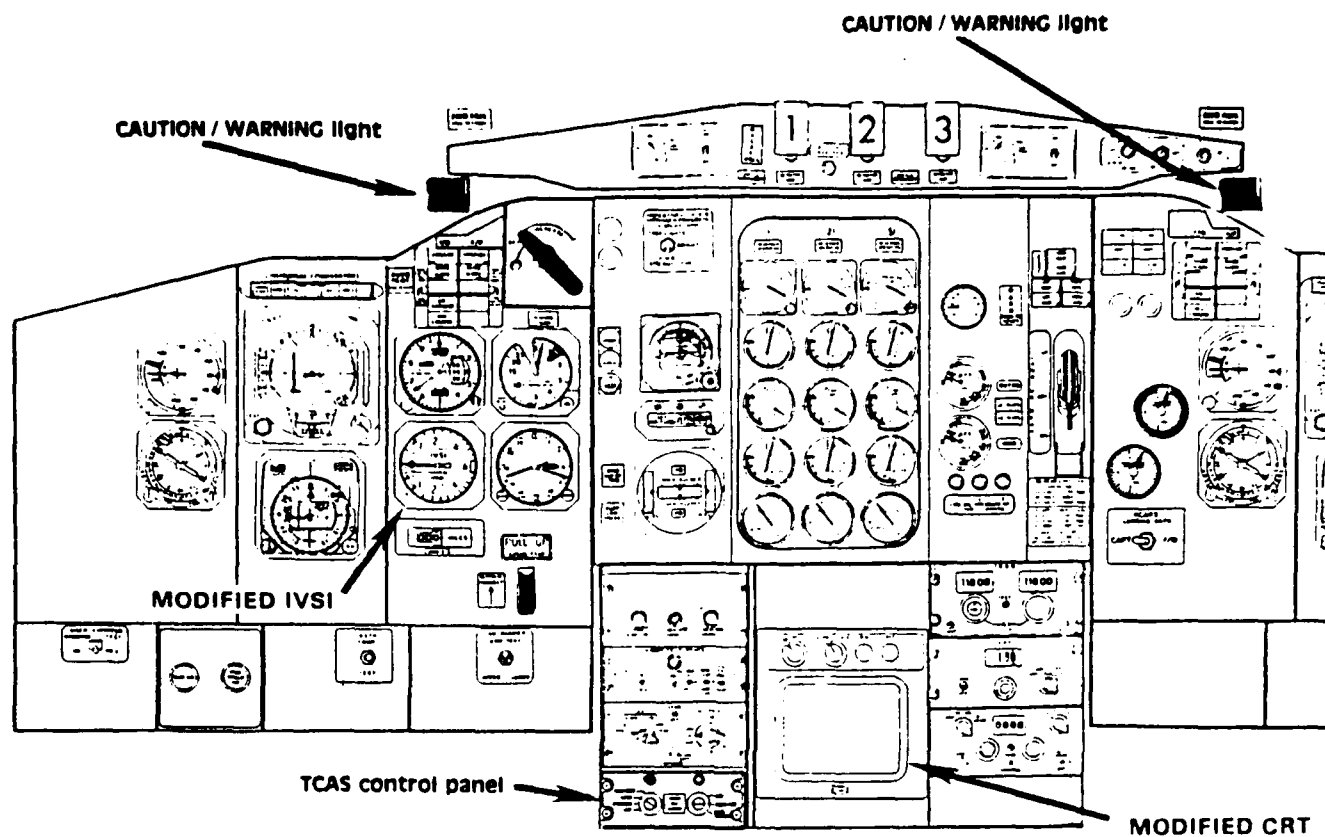


FIGURE 2-4

TCAS COCKPIT EQUIPMENT LOCATION

#### 2.5.4.3 Symbol Generator

The symbol generator receives display data from the RF electronics unit via an RS-232 bus and converts these data into real-time video and timing signals that are compatible with the aircraft's weather radar indicator.

#### 2.5.4.4 Antenna System

Two dedicated antennas are used for TCAS. The top antenna is a custom, low-profile antenna that transmits directionally and receives omnidirectionally. The antenna consists of four elements that are used to provide the directional capability. The omni receive mode of the antenna uses the four elements, which provide separate but simultaneous beams for 360-degree coverage. The angle of arrival of a reply is derived from these four beams in the computer unit. The antenna does not require engine bleed air for de-icing purposes.

The bottom antenna is a standard omni blade antenna; it is used for both interrogation and reception of replies.

#### 2.5.4.5 Control/Display Unit

The control/display unit serves as the driver for the IVSIs. It receives display inputs from the RF electronics unit and provides a voltage signal to the IVSIs to illuminate the proper arrow or segment lights.

#### 2.5.4.6 TCAS Control Panel

The TCAS Control Panel is located on the left side of the Forward Electronic Control Panel of the cockpit. It contains two switches that control the operation of TCAS (OFF, STANDBY, AUTO, SELF TEST) and the connection of TCAS to the system displays (WX, TCAS/WX, TCAS/TRACKS). The control panel also contains two status lights to indicate that power is applied to the TCAS equipment and that a failure has been detected. The control panel is illustrated in Figure 2-5.

#### 2.5.4.7 Recorder

The recorder is a cassette recorder that operates in an event-driven mode to record selected data on TCAS encounters. It is controlled by the computer unit, which determines the type and quantity of data to be recorded. During the evaluation, data were recorded when the flight crew performed a TCAS SELF TEST and when any type of TCAS data was presented to the flight crew.

The recorder also contained a time-of-day (TOD) clock that provided TOD information to the recording system. The TOD was recorded, together with other TCAS data, to facilitate the correlation of the electronically recorded data with the data provided by the cockpit observers and flight crews.

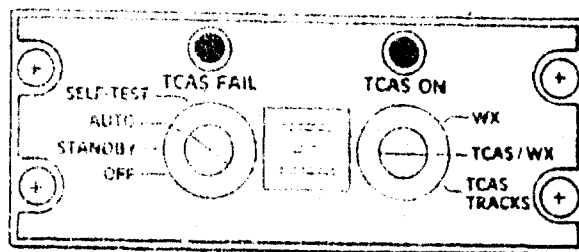


FIGURE 2-5

TCAS CONTROL PANEL.

## 2.5.5 Installation Problems

Several problems were encountered during the modification of the TCAS aircraft and during the subsequent installation and check-out of the avionics and data recording equipment. Although these problems were typically minor and the solutions were straightforward, it often took several hours to isolate a problem. The problems are summarized in the following paragraphs.

### 2.5.5.1 Drawing Packages

The most significant problem encountered during the installation occurred while the wiring and equipment racks were being installed in the aircraft. The wiring and aircraft provisions were completed in accordance with documentation supplied by Dalmo Victor. Unfortunately, the documentation provided to Piedmont did not incorporate the latest configuration of the TCAS avionics. This error required that Piedmont make several significant changes to the installation.

### 2.5.5.2 Grounding

The aircraft provided grounding for each display and avionics component. However, testing of the TCAS equipment on the aircraft indicated that the original grounding locations for the cockpit displays were not adequate. The problem manifested itself in the faulty operation of the Caution/Warning lights and the CRT display.

When power was applied to the system, there was leakage from the +28 VDC power input, causing the Caution/Warning lights to be dimly illuminated. In the original installation, the ground for the power

input was provided through the RF electronics unit located in the E&E bay. This problem was corrected by providing a ground on the glare-shield.

Another problem was noted on the CRT display while TCAS information was being displayed: "ghosting" of the intruder aircraft symbol and altitude data block. The problem was isolated to a poor ground between the CRT indicator case and the airframe. After an additional ground wire was installed between the case and the airframe, the problem disappeared.

#### 2.5.5.3 Sneak Path from Landing Gear

During a ground check-out of the system, a sneak circuit was found between the Landing Gear Accessory Unit and the engine-idle switch. It was discovered that the TCAS displays were inhibited with the flaps fully retracted. The conditions for inhibiting the CRT display are resident in the TCAS software as follows:

- Altitude lower than 1,000 feet AGL
- Landing gear down and locked
- Flaps greater than 25 degrees

During the ground installation test, the throttle levers were inadvertently advanced, then pulled back to idle. This sounded the gear warning horn, which was silenced by using the horn cutout switch on the center console. After this cutout switch was used, it was noticed that the CRT would not display traffic information.

An examination of the airplane installation drawings revealed a sneak path between the engine-idle switch and the Flap Discrete input to TCAS. When the throttles were advanced and retracted and the horn cutout switch pulled, the Flaps Discrete input to TCAS was grounded, giving the appearance that the flaps were extended beyond 25 degrees. An isolation diode was installed in the wiring between the engine-idle/gear horn circuit and the flaps-down/TCAS circuit to correct the problem.

## 2.6 AVIONICS CERTIFICATION

Before installing any type of equipment on board an air carrier aircraft, it is necessary to receive FAA approval. Approval is granted and the equipment certified for use on the aircraft after a detailed review of the equipment design, the aircraft installation, and the equipment operability. This certification process is intended to provide assurance that a new or modified piece of equipment can be safely operated on board an aircraft without degrading the operation of other aircraft systems.



The certification of TCAS for this evaluation was handled by the Atlanta Aircraft Certification Office (ACO), with additional technical guidance provided by the FAA's Central Region and FAA Headquarters. The certification requirements were developed by the ACO in conjunction with ARINC Research and Piedmont Airlines. The certification activities were conducted in accordance with established ACO practices, because TCAS would be operated in Piedmont's normal revenue service.

The initial discussions with the ACO centered on the criticality of TCAS. It was decided to conduct the certification under the auspices of section 25.1309 of the Federal Aviation Regulations (FAR) and Advisory Circular (AC) 25.1309 (Reference 6). AC 25.1309 defines three classifications of the probability of encountering a system failure condition: probable, improbable and extremely improbable. These classifications are related to failure conditions that have increasing impact on safety. On the basis of these classifications, airplane functions are classified by AC 25.1309 in the following manner:

- **NON-ESSENTIAL** - Functions whose failures would not contribute to or cause a failure condition which would significantly impact the safety of the airplane or the ability of the flight crew to cope with adverse operating conditions. Airplane conditions which result from improper accomplishment or loss of non-essential functions may be probable.
- **ESSENTIAL** - Functions whose failures would contribute to or cause a failure condition which would significantly impact the safety of the airplane or the ability of the flight crew to cope with adverse operating conditions. Failure conditions which result from improper accomplishment or loss of essential functions must be improbable.
- **CRITICAL** - Functions whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the airplane. Failure conditions which result from improper accomplishment or loss of critical functions must be extremely improbable.

Because of the proposed flight crew procedures, the ACO and FAA Headquarters decided that the Phase II evaluation must be conducted with avionics certified at the Essential level. This determination meant that ARINC Research had to present to the ACO data showing that the probability of encountering an undetected TCAS failure was on the order of  $1 \times 10^{-5}$  or lower per hour of flight.

#### 2.6.1 Certification Requirements

Using the guidance contained in AC 25.1309 and experience gained through previous certification work, the ACO defined the documentation required to access the avionics to be operated at the Essential

level. The certification requirements were grouped into three areas: (1) results of avionics level testing and analyses, (2) results of ground tests of the avionics conducted aboard the aircraft, and (3) results of flight tests.

To complete the ground tests and flight tests in an efficient manner, the ACO approved a request to use the FAA's B-727 for a majority of the ground and flight tests. This aircraft is configured for the conduct of various engineering evaluations, permitting easy access to the equipment to conduct portions of the ground test. In addition, the FAA aircraft was used for that portion of the flight test that required flying planned encounters against an intruder aircraft. With these tests performed at the FAA Technical Center, the ground and flight tests at Piedmont became functional checks that verified the aircraft/TCAS interfaces, rather than an engineering evaluation of TCAS.

The documentation required by the ACO is shown in Table 2-3. It was prepared by various organizations, including ARINC Research, Dalmo Victor, Piedmont Airlines, The MITRE Corporation, and the FAA Technical Center. The documentation was compiled, reviewed, and submitted to the ACO by ARINC Research. After reviewing each document, the ACO either approved the submittal or requested that additional data be provided. ARINC Research acted as the focal point for responding to these requests for additional data and for clarifying any questions on the submitted data.

#### 2.6.2 Certification Testing at Dalmo Victor

Two phases of certification testing were completed by Dalmo Victor. The first concentrated on demonstrating that the avionics hardware performed its intended functions. These hardware tests included board-level electrical checks conducted during the manufacturing cycle, line replaceable unit (LRU) testing, and system integration testing. The hardware testing culminated with the successful performance of the Factory Acceptance Test Procedure (FATP), a comprehensive test verifying that the avionics were performing as designed. A formal test procedure prepared by Dalmo Victor and approved by the FAA, the FATP was completed before the avionics were delivered to the FAA. The test was witnessed by personnel from the TCAS Program Office and the FAA Technical Center.

The hardware testing was thorough and was completed very early in the certification process. However, the software development was conducted in a less rigorous manner, with very little documentation being maintained during the software development effort. As a result, it was not possible to present to the ACO data demonstrating that the probability of a software error was improbable. This caused a significant delay in receiving the STC. To correct this deficiency, a major effort was undertaken by Dalmo Victor, the FAA Technical Center, MITRE, and ARINC Research to produce the documentation and test results needed to demonstrate that the avionics could be certified at the Essential level. A major portion of this effort concentrated on developing software tests that exercised each logic step in the CAS and

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Table 2-3. TCAS Certification Documentation Requirements

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Acceptance Test Plan  
Acceptance Test Report  
No Technical Objection  
    Letter on PPI-1U Modification  
DO-160A Compliance Statement  
Drawings on PPI-1U Modification  
IVSI TSO Letter  
Electrical Load  
    Analysis, N40  
Electrical Load Analysis, N857N  
Structural Analysis, N40  
Structural Analysis, N857N  
  
EMI Analysis Plan, N40  
EMI Analysis Report, N40  
EMI Analysis Plan, N857N  
Statement of No Skin  
    Map Requirement  
Boeing Letter on No  
    Antenna Icing Hazard  
  
Failure Mode and Effects  
    Analysis of Interfaces  
Airplane Flight Manual Supplement  
Top Drawing of TCAS  
List of TCAS Drawings  
Installation Drawings, N40  
  
Installation Drawings, N857N  
Detail Drawings of Parts  
    Manufactured for N40  
Detail Drawings of Parts  
    Manufactured for N857N  
Ground Test Plan, N40  
Ground Test Plan, N857N  
Flight Test Plan, N40  
Flight Test Plan, N857N  
Equipment Conformity  
    Tags for TCAS Equipment  
DO-178 Documentation  
FAR 25.1309 Substantiation

Note: N40 is the FAA Technical Center B-727, and N857N  
Is the Piedmont B-727 used in this evaluation.

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and surveillance software. The FAA Technical Center developed a series of encounter scenarios that could be run against the system's compiled software. These scenarios, which tested every line of the TCAS software, were approved by the ACO and performed by Dalmo Victor; the results were then reviewed by the ACO.

In addition to performing these software tests, Dalmo Victor and ARINC Research prepared documentation on the software development effort to support the ACO's analyses. This documentation included a Programmer's Manual, a System Design Description, and a Software Configuration Management/Quality Assurance Plan.

### 2.6.3 FAA Technical Center Testing

After the hardware testing was completed at Dalmo Victor, the avionics were delivered to the FAA Technical Center and installed in its Boeing 727. Prior to initiating any certification testing, the Technical Center performed a variety of tests, including electromagnetic compatibility/interference tests, antenna pattern measurements, and various system accuracy tests, to validate the performance of the avionics. A major portion of the Center's testing consisted of flights in which TCAS was used while the B-727 flew planned encounters against other FAA aircraft. These development flight tests identified several problems in software logic, software coding, and hardware performance. The problems were corrected and the flight tests repeated to verify the solutions. Reference 1 provides the details of the Technical Center's testing and the problems identified during the testing.

The Technical Center also conducted an operational evaluation of TCAS using pilots from various airlines. These pilots were invited to the Technical Center, trained in the operation and use of TCAS, and given the opportunity to fly several planned encounters. The evaluation identified several human factors issues related to the system's displays and caused some concern regarding the TCAS Invalid feature (see Section 2.7) of the system. The human factors issues were resolved by modifying the colors used in the displays and changing the aural messages. These issues are discussed in detail in Reference 1. The TCAS Invalid concerns were never fully resolved, and the TCAS Invalid advisory remained an integral feature of TCAS during the Phase II evaluation.

Following the completion of these pre-certification tests, the Technical Center began to support the certification effort. The Technical Center also made a major contribution towards completing the requirements of the Type Inspection Authorization (TIA). The TIA defined the certification ground and flight tests required to demonstrate that TCAS worked properly, without affecting the operation of other aircraft systems, after being installed on the aircraft. Most of the TIA requirements were completed at the Technical Center. The ground testing included antenna (system) bearing accuracy checks, tests of electromagnetic interference with all other aircraft avionics, verification of the mutual suppression bus/TCAS interface, and proper operation of all displays. These tests were conducted by FAA Technical Center personnel and witnessed by the ACO.

After successful completion of the ground tests, two ACO flight test pilots completed the flight test portion of the TIA. Their evaluation included flying numerous planned encounters, assessing the quality and volume of the audio annunciations, assessing the readability of the displays under various lighting conditions, and evaluating the possibility of conflicting advisories from TCAS and the Ground Proximity Warning System. The flight test evaluation produced several operational concerns that were addressed by a minor software change and modifications to the proposed operational procedures. The concerns from this flight test are outlined in Reference 2, and the responses to the concerns are detailed in Reference 3.

#### 2.6.4 Certification Testing at Piedmont

Following completion of the FAA Technical Center testing in February 1986, the avionics were delivered to the Piedmont Airlines Maintenance Facility in Greensboro, North Carolina, where they were installed in the TCAS aircraft. The modifications to the TCAS aircraft had already been completed, tested, and inspected by an FAA Maintenance Inspector. Thus it was necessary only to install the avionics, displays, and recording equipment, and to verify that the system operated properly. This was completed in early March 1986, and the ACO was notified that the remainder of the TIA could be completed.

The certification testing at Piedmont consisted of both ground tests and flight tests. The ground tests were a subset of the ground tests already conducted at the Technical Center; they concentrated on verifying the interfaces between TCAS and other aircraft systems.

The flight tests concentrated on verifying the interfaces between the TCAS system and pilots and between TCAS and other aircraft systems. The Piedmont flight test did not include any encounters with other aircraft; instead, a transponder antenna located on a hangar roof was used to simulate an intruder aircraft. In addition to the flying portion, the test pilot also evaluated the brightness of the TCAS displays in simulated darkness.

The testing was completed at Piedmont on March 21, 1986. The ACO reviewed the data from the testing conducted both at Piedmont and at the FAA Technical Center and issued TIA Number 100-100 to Piedmont Airlines on April 15, 1986.

#### 2.7 DEVELOPMENT OF FLIGHT CREW PROCEDURES

Since a primary objective of this project was to assess a flight crew's use of TCAS, procedures were developed to enable a flight crew to use the full capability of the system. These procedures were jointly developed by Piedmont Airlines, the FAA, and the ACO. The basic premise of these procedures was that the flight crew should be able to respond to a TCAS Warning without having to leave the cockpit in flight.

After successful completion of the ground tests, two ACO flight test lots completed the flight test portion of the TIA. Their evaluation included flying numerous planned encounters, assessing the quality and volume of the audio annunciations, assessing the readability of the displays under various lighting conditions, and evaluating the visibility of conflicting advisories from TCAS and the Ground Proximity Warning System. The flight test evaluation produced several operational concerns that were addressed by a minor software change and modifications to the proposed operational procedures. The concerns from this flight test are outlined in Reference 2, and the responses to the concerns are detailed in Reference 3.

#### 6.4 Certification Testing at Piedmont

Following completion of the FAA Technical Center testing in February 1986, the avionics were delivered to the Piedmont Airlines Maintenance Facility in Greensboro, North Carolina, where they were installed in the TCAS aircraft. The modifications to the TCAS aircraft had already been completed, tested, and inspected by an FAA Maintenance Inspector. Thus it was necessary only to install the avionics, displays, and recording equipment, and to verify that the system operated properly. This was completed in early March 1986, and the ACO was notified that the remainder of the TIA could be completed.

The certification testing at Piedmont consisted of both ground tests and flight tests. The ground tests were a subset of the ground tests already conducted at the Technical Center; they concentrated on verifying the interfaces between TCAS and other aircraft systems.

The flight tests concentrated on verifying the interfaces between the TCAS system and pilots and between TCAS and other aircraft systems. The Piedmont flight test did not include any encounters with other aircraft; instead, a transponder antenna located on a hangar roof was used to simulate an intruder aircraft. In addition to the flying portion, the test pilot also evaluated the brightness of the TCAS displays in simulated darkness.

The testing was completed at Piedmont on March 6, 1986. The ACO reviewed the data from the testing conducted both at Piedmont and at the FAA Technical Center and issued STC Number SA192650 to Piedmont Airlines on April 15, 1986.

#### 7 DEVELOPMENT OF FLIGHT CREW PROCEDURES

Since a primary objective of this evaluation was to assess a flight crew's use of TCAS, procedures were developed to enable a flight crew to use the full capability of the system. The initial procedures were jointly developed by Piedmont Airlines, ARINC Research, and the FAA. The basic premise of these procedures was that a crew should be able to respond to a TCAS Warning without having the intruder aircraft in sight.

From this premise and the design and limitations of the system's displays, the procedures shown in Tables 2-4 and 2-5 were developed. These procedures were partially validated during the FAA Technical Center's operational evaluation (see Section 2.6.3) and further refined during the development of Piedmont's flight crew training program.

Table 2-4. TCAS Caution Procedures

MEMORY	
CRT DISPLAY VISUAL SEARCH FOR TRAFFIC	OBSERVE ACCOMPLISH CAPTAIN, FIRST OFFICER ALL
Advisory	Pilot Response
CAUTION	If threat traffic is visually acquired, maintain visual acquisition to ensure safe separation.

NOTE: TCAS Caution information displayed on the weather radar indicator is for information only and is not to be used as a basis for maneuvering to avoid a threat aircraft.

## 2.8 FLIGHT CREW TRAINING PROGRAM

To ensure that a flight crew had an understanding of the TCAS avionics and to ensure that they could safely use the information displayed by the system, a training program was developed and implemented prior to the first TCAS flight in revenue service. The following subsections define the contents of this training program, the validation of the training program, and several areas that should receive more emphasis in subsequent TCAS training programs.

### 2.8.1 Training Approach

A training program that could be implemented at Piedmont's B-727 crew bases was developed. The initial effort was directed toward developing a stand-alone video tape that the pilots could view independently before flying the TCAS aircraft. Several versions of such a training video were produced at the FAA Technical Center before this training concept was determined to be inadequate for the evaluation.

The FAA's Office of Flight Standards and Piedmont's Principal Operations Inspector (POI) requested that a more detailed training program be implemented. The FAA recommended that this revised training program provide some type of hands-on training to better acquaint the

Table 2-5. TCAS Warning Procedures

MEMORY		
VISUALLY CLEAR AIRSPACE	ACCOMPLISH	CAPTAIN
VERTICAL RATE (IF NECESSARY)	ADJUST	CAPTAIN
RETURN TO LAST CLEARANCE	ACCOMPLISH	CAPTAIN
Advisory	Pilot Response	
CLIMB	Smoothly establish a climb rate of 1500 fpm. If climb rate is in excess of 1500 fpm when warning sounds, maintain the greater rate.	
DESCEND	Smoothly establish a descent rate of 1500 fpm. If descent rate is in excess of 1500 fpm when warning sounds, maintain the greater rate.	
LIMIT VERTICAL RATE	<ol style="list-style-type: none"> <li>1) Maintain vertical rate out of lighted segments.</li> <li>2) If vertical rate is out of lighted segments, DO NOT change the vertical rate.</li> <li>3) If vertical rate is in the lighted segments, change the vertical rate so that the vertical rate is out of lighted segments.</li> </ol>	
TCAS INVALID	With visual acquisition of threat traffic, maneuver visually to assure safe separation. Without visual acquisition, discontinue any previously initiated maneuver based on TCAS IVSI information, clear the airspace, and return to and/or maintain last clearance.	
WARNING DISCONTINUED	Discontinue any vertical maneuver based on TCAS IVSI information and smoothly return to and/or maintain last assigned clearance. Minimize the deviation from last assigned clearance.	

(Continued)



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Table 2-5. TCAS Warning Procedures (continued)

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NOTES TO TCAS WARNINGS PROCEDURE

1. Altitude-Crossing Maneuver - An altitude-crossing maneuver occurs when two aircraft having an initial vertical separation interchange vertical positions as a result of a TCAS Warning. As a result of following the TCAS Warning, the TCAS aircraft and the threat aircraft will pass through the same altitude. An altitude crossing is necessary in some situations to ensure that adequate vertical separation is provided.
2. TCAS/GPWS Interaction - If for any reason TCAS issues a DESCEND advisory at the same time as a GPWS alert, the GPWS alert takes precedence.
3. LIMIT VERTICAL RATE Warnings - TCAS may issue a LIMIT VERTICAL RATE Warning when no changes are required to the existing vertical speed. These preventive advisories are issued to ensure that any change to the vertical speed does not reduce the projected safe separation at the closest point of approach. Therefore, it is unnecessary to alter the vertical speed when the rate-of-climb needle is out of the lighted segments. Under no conditions is it necessary to leave an assigned altitude when a LIMIT VERTICAL RATE Warning is received.
4. Expected Altitude Deviations - A majority of TCAS situations that require a deviation from an ATC clearance are usually resolved with altitude deviations of 500 to 800 feet. To minimize the impact of a TCAS maneuver on the ATC system, it is essential that you periodically cross-check the IVSI during a TCAS maneuver so that changes in the WARNINGS can be quickly detected and deviations from the original clearance can be minimized.
5. TCAS Invalid - This advisory is issued either when a pilot elects not to respond to a TCAS Warning because the traffic is in sight or when the traffic performs a maneuver that changes its predicted flight path after a Warning is issued. When you receive this Warning, discontinue any TCAS maneuver, clear your airspace, and return to your assigned altitude.
6. Caution/Warning Lights and Aural Annunciations - These lights and annunciations may be silenced at your discretion by depressing either the captain's or first officer's Caution/Warning lights.

crews with using TCAS and to verify the proper transfer of information to the crew members. After reviewing the recommendation, Piedmont, ARINC Research, and the TCAS Program Office determined that resources were not adequate to permit the implementation of hands-on training. Instead, a training concept using video as the primary training aid was developed. The information in the video was reinforced with a review of the TCAS Operations Manual Supplement by a stand-up instructor, who answered questions raised by the pilots. The contents of the video tape were also revised to emphasize operationally oriented issues rather than engineering and TCAS theory of operation.

These training program modifications satisfied a major portion of the POI's concerns, but they did not verify the transfer of information to the crew members. To satisfy this concern, a written quiz was added to the end of each training session. The quiz showed the crew displays from encounters flown in Piedmont's simulator. The displays and sample encounters were included at the end of the training video. At selected points in the encounter, the video was stopped and the pilots were asked to respond to questions about the meaning of the displayed data and the appropriate response. Pilots receiving the training had to receive a grade of 100 on the quiz to become TCAS-qualified. If the grade was less than 100, additional instruction was provided and the pilot was tested again with a second set of questions and encounters. If the second quiz was not passed, the pilot was not considered trained and had to repeat the TCAS training at a later date. There were no reported instances of a pilot's failing both quizzes.

After the POI approved the training concept, the selected TCAS instructors were assembled at Piedmont's training facility in Winston-Salem, North Carolina. These instructors were Piedmont's chief pilots, assistant chief pilots, and check airmen. They received the TCAS pilot training course and an extensive review of TCAS operation and its limitations, and then flew several encounters in the simulator. The TCAS instructors returned to their assigned crew bases and implemented the training program for the pilots assigned to their domiciles. The contents of the TCAS training program are detailed in Appendix A.

The guidelines for this evaluation stipulated that both the captain and the first officer must be qualified in the use of TCAS in order to operate the system. The second officer was also encouraged to attend a TCAS training session. The POI's approval of this training program called for 1-1/2 hours to be allocated for TCAS training. Further, the initial approval required that the training be conducted within five days of a pilot's first flight with TCAS. After the first 100 hours of the evaluation, this requirement was relaxed to allow seven days between training and first flight.

#### 2.8.2 Training Program Validation

Because of the POI's concerns, as addressed in Section 2.8.1, Piedmont and ARINC Research were required to demonstrate that the proposed training program permitted the crews to use the system without degrading the safety of flight. The training program validation was

was conducted at Piedmont Airlines with Piedmont's Boeing 727 simulator. ARINC Research and Piedmont modified the simulator to provide a TCAS capability. The TCAS installation in the simulator includes all TCAS displays and aural annunciations, an intruder aircraft in the visual scene, and a menu of 19 pre-defined encounters. The selection menu also enables the instructor to create unique encounters by changing one or more of the five parameters defining the 19 fixed encounters. A block diagram of the TCAS simulation is shown in Figure 2-5.

The validation was conducted by ARINC Research and Piedmont personnel and witnessed by the FAA's Office of Flight Standards (AFS). It consisted of giving the TCAS training to pilots undergoing their annual or semiannual proficiency checks and simulator courses. Once the pilots had completed the TCAS training, they moved to the simulator, where a maximum of six encounters were flown. The pilots' responses to advisories were recorded to permit an evaluation of response time, deviation from assigned altitudes, and vertical rates used during the response. In addition, the pilots' actions in using TCAS were monitored by AFS personnel to assess the pilots' understanding of the displayed information and their use of the system.

Three evaluations were conducted in 1986 and 1987. AFS believed that the results of the first two evaluations did not demonstrate a complete understanding of the system and operational procedures. The data from the first evaluation demonstrated that the pilots responded to advisories in a timely manner, did not maneuver on TCAS Cautions, did not respond differently during altitude crossing encounters, and generally understood the displayed TCAS data. However, the data and AFS observations also showed that two pilots responded too aggressively and obtained vertical rates of up to 3,000 feet per minute (fpm) when responding to a CLIMB or DESCEND TCAS Warning. These aggressive responses resulted in excessive deviations from the assigned altitude. On the basis of these data, the proposed training program was disapproved.

The training program was revised to include additional emphasis on using a vertical rate of 1,500 feet per minute to respond to TCAS Warnings and minimizing deviations from assigned clearances. The video tape and operations manual were revised to reflect this emphasis, and a second evaluation effort was initiated. A major display-interpretation problem was detected during that evaluation. During an encounter that caused a LIMIT VERTICAL RATE TCAS Warning (DO NOT CLIMB > 2,000 FPM), a pilot established a 2,000 fpm rate of climb after receiving the Warning in level flight. During the debrief, the pilot stated that he interpreted the display as a command to establish a 2,000 fpm rate of climb, i.e., that the IVSI display represented a vertical speed target. By establishing a 2,000 fpm climb rate, the vertical separation with the intruder was decreased.

On the basis of this encounter, the training program was again revised to provide additional emphasis on the response to a LIMIT VERTICAL RATE TCAS Warning. The emphasis was added to the video tape and to the Operations Manual Supplement. The revision also included the development of the TCAS quiz and a detailed training syllabus that

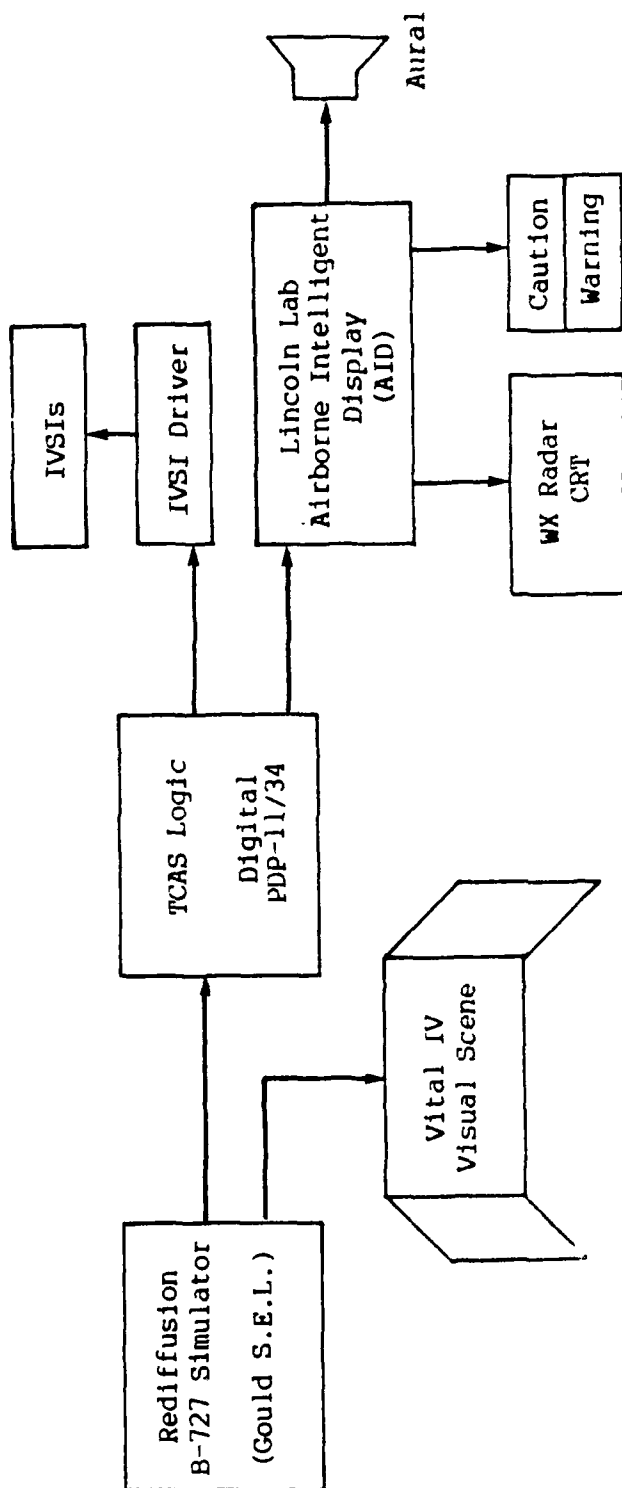


FIGURE 2-6

PIEDMONT AIRLINES' TCAS SIMULATION CONFIGURATION

defined the material to be covered and the portions of the training program requiring particular emphasis. The syllabus was provided to all TCAS instructors as a guide for their training sessions. The quiz was added to verify the transfer of information during training.

With this version of the training program, a third evaluation was initiated. It was conducted in the same manner as the previous two, and no significant problems were detected. The data showed that the training program developed by Piedmont and ARINC Research was an effective method of instructing the flight crews in the use of TCAS. However, the results of this evaluation did result in an FAA request for a few minor, editorial changes in the video portion of the tape and in the wording of the Operations Manual. These changes were made and the training program was approved by the POI.

### 2.8.3 Training Program Effectiveness

The training program used in the Phase II evaluation was effective in teaching the flight crews how to interpret the TCAS displays and respond to TCAS-generated advisories. During the evaluation, there were no significant TCAS operational problems resulting from deficiencies in the training program. This assessment is based on written comments received from the pilots participating in the evaluation and the TCAS observers.

There was no apparent difference in the use of the system by the pilots who received their TCAS training entirely at the crew domiciles and those who had received a TCAS demonstration in the simulator or had participated in one of the training program validation efforts. None of the pilot and observer comments received during the evaluation indicated that more extensive training, i.e., simulator training, was required to operate the system. One observer and several pilots commented that simulator training may have increased the crews' familiarity with the system, but none stated that it was necessary for safe operation.

Although the Phase II training was effective, there were some areas that should receive additional emphasis in future training programs. A portion of these problems may be attributed to any given crew's limited exposure to the system. Since only one aircraft was equipped with TCAS, an individual pilot saw the system on an irregular basis. The crews were therefore unable to become familiar with the details of the system's operation under varying conditions of altitude and aircraft configuration. The crews asked questions that were generally related to the TCAS design and system operating parameters such as interrogation range, TCAS/TRACKS mode parameters, and antenna mask angles. These details were intentionally omitted from the training program, since they were not considered necessary for operating and using the system. While the inclusion of these details in a TCAS training program is probably

inconsistent with other avionics training, it may be desirable to have additional technical information available for pilots who want to learn more about the system.

One area that should receive greater emphasis is the interpretation of a "No Bearing" display. When an intruder is being tracked only on the bottom, omni antenna, TCAS is unable to display the relative bearing of the intruder aircraft, but is still able to determine the intruder's range and relative altitude (if the intruder is equipped with Mode C). Therefore, TCAS can still issue TCAS Cautions and TCAS Warnings. Instead of displaying the intruder at the proper bearing, the CRT shows the intruder's range and relative altitude (if available) in a tabular display. "No Bearing" TCAS Cautions are shown in amber, and TCAS Warnings are shown in red -- in the same way as if bearing information were available. The crews often had questions on the meaning of a "No Bearing" display, even though the training program and Operations Manual included a discussion of this display format. On one or two occasions a "No Bearing" TCAS Caution was displayed at the same time as a blue Proximity target (no threat) with bearing information available. The crews initially looked for the Proximity target instead of the Caution target. Future training programs should provide examples of "No Bearing" encounters to ensure that the crews know how to interpret this display.

Another area that should be addressed is the interface with other cockpit controls, especially interfaces that result in changes to the existing operations of the affected equipment. For example, in Piedmont's Phase II equipment installation, the normal operation of the weather radar was affected. The weather radar indicator has a three-position switch labeled HOLD, SCAN, and LIST. The normal position of this switch is SCAN; however, the design of the TCAS required that the indicator be placed in the LIST position when the weather radar was in STANDBY in order for it to display TCAS information. When the radar was turned ON, it was necessary to return the indicator to the SCAN position. This non-standard operation caused a great deal of confusion during the Phase II evaluation, especially since the TCAS aircraft was the only Piedmont aircraft that required the use of the LIST mode. As a result, several TCAS Cautions were not displayed to the flight crew after the aural annunciations were provided.

No other training-related problems were observed in the Phase II evaluation.

## 2.9 OBSERVER PROGRAM

An integral part of the Phase II evaluation was the participation of the cockpit observers. An observer was required to be on board for TCAS to be operated. The observers were volunteers from various segments of the aviation industry. Organizations such as the FAA, the Air Line Pilots Association, the Air Transport Association of America, and FAA contractors were asked to provide candidate lists of observers to support the Phase II evaluation. These lists were reviewed and approved by the TCAS Program Office, and cockpit authorizations were provided by

the FAA's Carolina Flight Standards District Office. The observers generally possessed extensive backgrounds in airline operations and a working knowledge of TCAS and the Phase II evaluation.

The role of the observer was to record parameters on a crew's use of TCAS and provide an opinion of TCAS impacts on the flight crew and ATC. After each TCAS Caution and Warning, the observers recorded information on the TCAS aircraft's location and altitude, aircraft configuration, flight conditions, type of intruder, sequence of events, flight crew workload, ATC situation, type of TCAS advisory, and crew response to the TCAS advisory. The observers did not assist the flight crew in interpreting the TCAS displays or resolving an encounter situation during an encounter. However, they acted as a source of TCAS information for the flight crews and answered specific questions from the crews.

After the observer list was finalized, several observer training sessions were held. The observers were indoctrinated in the objectives of the Phase II evaluation, completed the flight crew training program, and received instruction on the desired data and the observer data collection forms. They were also instructed on administrative procedures for obtaining jump seat passes, submitting their data, and scheduling observers. Each training session also provided an opportunity for the observers to ask questions and discuss the training material. The materials used in these training sessions are shown in Appendix B.

The trained observers were scheduled for two-day and three-day trips with the TCAS aircraft. The data recorded by the observers were valuable in recreating several encounters of interest (see Chapter Five) and identifying problems in system operation and crew operational procedures.

## CHAPTER THREE

### DATA COLLECTION

Data requirements and the available data sources were analyzed early in the project's planning phase. Three major data sources were identified: (1) performance data produced within the TCAS avionics, (2) opinions and observations from pilots and cockpit observers, and (3) tracking data and voice tapes from ATC facilities. The methodologies and collection techniques were outlined for each source of data, and the best source, from an ease-of-collection viewpoint, was selected for each type of data.

#### 3.1 DATA COLLECTION METHODS

##### 3.1.1 Observer Notes

Cockpit observers with an extensive background in either airline operations or TCAS design and operation collected qualitative data on the operational effectiveness of TCAS. Observers were provided by various organizations (see Section 2.9) and scheduled by ARINC Research. The TCAS observers recorded objective data on the location, flight conditions, and configuration of the test aircraft for each TCAS Caution and TCAS Warning. Objective data were also provided on the sequence of events in each encounter, the geometry of the encounter, and any flight crew/ATC interaction regarding the encounter.

In addition to these objective data, the observers were asked to provide subjective data on the utility of TCAS in the cockpit and any impacts to normal crew and ATC actions caused by TCAS. To accomplish this, the observers recorded data on crew responses to TCAS advisories; any display interpretation or operational procedure discrepancies; deviations from normal (non-TCAS) cockpit action during an advisory; communications with ATC; and deficiencies or potential problems with the TCAS displays' symbology, location, and implementation.

The observers were also asked to obtain and record comments and questions by the flight crews. They recorded comments made during and immediately after a TCAS advisory and interviewed each crew at the completion of a trip. Since a major objective of the Phase II evaluation was to obtain the opinions of flight crews on the use of TCAS, the post-



flight interviews concentrated on obtaining pilots' views on the TCAS procedures, training, and display format and location. The pilots were offered the opportunity to provide additional written comments, but few pilots had any significant comments that they felt needed a detailed explanation.

The observers were provided with forms to complete for each Caution, each Warning, and each crew. Copies of these forms are reproduced in Appendix C. The completed forms were returned to ARINC Research for distribution and analysis. The objective information contained on these forms were entered into a data base for further analysis and the subjective data were reviewed manually to detect problems areas or potential problem areas.

Periodically, the information from the observer forms was compared with the data collected from the tape recorder to assess both the avionics' performance and the crew response to advisories. These comparisons concentrated on the TCAS Warnings because the Warnings often advised a change in the test aircraft's trajectory. Each Warning received during the evaluation was reviewed in detail while Cautions were reviewed in detail only when a displayed Caution was questioned by an observer or pilot. The recorded data for each Caution were routinely reviewed by MITRE and the observer data for each Caution were reviewed by ARINC Research.

### 3.1.2 Automatic Data Recording

The Phase II TCAS installation includes two pieces of equipment that are unique to the evaluation and would not be required in operational installations. These are a digital tape recorder and a time-of-day clock, both used solely to collect time-marked data on encounter situations detected by the TCAS avionics.

The TCAS processor provides an RS-232 output to the recorder, which permits the recording of both surveillance and CAS data once per second during a TCAS advisory (Caution or Warning). The clock provides time-of-day and date data for time-stamping the data received from the processor.

The data recording equipment operated in an event-driven mode, and data were recorded whenever a Caution or Warning was issued, the TRACKS mode was selected, or a SELF TEST was performed. The recording equipment operated automatically. The only interaction possible between the observer or flight crew and the data recording equipment was the deactivation of the recorder's circuit breaker located in the cockpit. The recorder controls were located on the recorder, which was installed in the E&E bay. The data tapes were periodically changed by Piedmont's avionics personnel.

The removed tapes were forwarded to Piedmont's avionics shop at Washington-National Airport. ARINC Research or FAA personnel picked up the tapes from the airport and delivered them to The MITRE Corporation for reduction and analysis. MITRE maintained all the recorded data in a

data base and performed detailed analyses on each TCAS Warning. After copying the data from the tape cartridges, MITRE wrote end-of-file words on the entire tape to ensure that next data recorded on the tape were readable. The tapes were then returned to Piedmont's avionics shops at Charlotte, North Carolina, and Washington-National for further use.

### 3.1.3 ATC Data

Data for analyzing TCAS encounters were also available from data and voice tapes recorded by the ATC facilities handling the TCAS aircraft. The logistics required to collect, extract, and correlate data from ATC sites prevented these data from being used on a routine basis. Instead, the ATC data were used to supplement the automatically recorded data and the observer notes. ARINC Research and the FAA's Air Traffic Operations Service (ATO) established a procedure for determining when ATC data were desired. After every TCAS Warning, ATO was advised of the details of the Warning, including location, type of warning, geometry, observed ATC interaction, and crew response. On the basis of these inputs, together with the observer's subjective comments, a decision was reached regarding the necessity of obtaining ATC data. ATC data were generally obtained if the observer, ARINC Research, or ATO had questions regarding the impacts of the advisory on ATC or if the encounter geometry resulted in an unusual situation such as a TCAS Invalid.

ATC data were also used when no data on a TCAS Warning were available from the TCAS data recorder. When this problem was detected, ATO was notified and requested to obtain the data from the appropriate ATC facility. These data were then used by MITRE to recreate the encounter and analyze the performance of TCAS during the encounter.

## 3.2 DATA COLLECTION PROBLEMS

During the Phase II evaluation, the test aircraft was flown for over 1,500 hours with the TCAS avionics available for use. During this time, the TCAS avionics were operated and observer data were collected for 828 hours of operation. The discrepancy between the time available for data collection and the actual data collection hours is due to three types of problems in the data collection: crew training requirements, aircraft scheduling, and observer scheduling.

In addition, hardware problems with the TCAS data recording system resulted in the loss of data from several TCAS Warnings during the first weeks of the evaluation. The data collection problems are discussed in the following subsections.

### 3.2.1 Crew Training Requirements

The initial FAA-approved flight crew training program required that a crew receive TCAS training within five days of its first flight on the TCAS aircraft. (This requirement was later extended to seven days.) Further, both the captain and the first officer were required to be trained for the crew to operate the system. These requirements,

especially the seven-day training requirement, resulted in the loss of a large quantity of data. Piedmont was able to train the crews, but changes in aircraft routing would often result in a crew's not flying the test aircraft within seven days. When this occurred, the pilot had to be retrained. Since both pilot and aircraft scheduling are dynamic processes, this situation arose frequently. Therefore, the aircraft was often operated with an untrained crew and no data were collected by the observer. However, whenever an untrained crew flew the test aircraft, they were requested to operate TCAS in STANDBY so that data could be recorded by the tape recorder.

### 3.2.2 Aircraft Scheduling

As previously stated, the test aircraft was not assigned any special routings and it operated within the normal Piedmont route structure. With the assistance of Piedmont's aircraft scheduling department, ARINC Research monitored the routing of the test aircraft. When the test aircraft (or other aircraft) experienced a mechanical problem that resulted in rerouting of the test aircraft, it often had an impact on the observer scheduling. In some cases, the rerouting made it impossible for the scheduled observer to meet the aircraft. Since a trained observer was required to be on board whenever TCAS was being used, the absence of an observer resulted in a loss of data.

### 3.2.3 Observer Availability

Data were also lost because of the unavailability of trained observers. Even though observers were generally scheduled a week or more in advance of their trips, their personal schedules would sometimes change and they would not be able to fly. Depending on the availability of other observers, it was often impossible to cover the original observer's flights. On other occasions, ARINC Research was unable to schedule any observers, and one or two days would pass without an observer on board. Whenever an observer was not available, no subjective data were collected.

### 3.2.4 Data Recorder Problems

The initial weeks of the operational evaluation were marked by several losses of data on critical TCAS Warnings. These data losses resulted from improper loading of data tapes and improper configuration of the data recorder.

Prior to the evaluation, instructions for changing tapes were forwarded to Piedmont's avionics personnel. These instructions provided a step-by-step guide for removing and installing tapes. However, there was apparently some confusion regarding the proper position of the power switch on the recorder, and the switch was sometimes placed in the OFF position. This problem was overcome by meeting with avionics personnel and providing additional information on the recorder's proper operating configuration.

Additional data were lost because the Write Protect cam on several data tapes was in the incorrect position. A review of the tape-handling procedures did not reveal how this cam was being reset, since MITRE always set the cam to the Write Enable position before shipping the tapes to ARINC Research. This problem was resolved by placing a piece of tape over the cam before returning the blank tapes to Piedmont.

Another data recorder problem was related to the interval between tape changes. Several tapes were received at MITRE with the tape completely full. The comparison of the data from these tapes with the observer notes indicated that some data were being lost after the tape was full. Since there is no cockpit indication of the recorder's status, there is no way for an observer or flight crew to determine if a tape is full. This problem was partially alleviated by changing data tapes every two or three days and after every TCAS Warning was received. Some data were still lost, since any two-day period is different from any other two-day period because of the routes flown and the pilot's use of the system.

During the last two weeks of the evaluation, no data were recorded because of a broken power switch on the recorder. Because of the impending completion of the evaluation, a decision was made to continue the evaluation without the recorder.

### 3.2.5 Time-of-Day Clock

The time-of-day clock is designed to mark the recorded data with a date and time stamp to assist in correlating the recorded data with the observer's notes. Throughout this evaluation, the presence of the time-of-day on the recorded data was intermittent. While this did not degrade the recording of the TCAS data, it made the correlation of recorded and observer data a tedious, manual process.

The data recording equipment was returned to Dalmo Victor on two occasions while the avionics were being repaired. The time-of-day signal is transmitted on an RS-232 bus from the clock, through the TCAS BEU, to the processor, where it is included with the data to be recorded. These time-stamped data are then transmitted back to the recorder via the BEU. No data dropouts were observed at Dalmo Victor; thus it was suspected that there was a problem in the aircraft. Since the time-of-day was the only data item observed to be missing, the RS-232 path from the processor to the recorder was assumed to be functioning properly. Extensive troubleshooting was performed on the aircraft, but the source of the problem was never detected. (Note: This same type of problem was observed throughout the Phase I evaluation.) The quality of the other recorded data was excellent throughout the evaluation.

### 3.2.6 Visual Acquisition Requirement

The first 400 hours of the Phase II evaluation were conducted with a requirement to visually acquire an intruder aircraft before responding to a TCAS Warning. Because there is no method for marking the recorded data with the time of visual acquisition, an accurate measure of pilot response time is not available from this data. Further, no attempts were made to measure the pilot's response time during this evaluation. This is not a major concern, since the results of the training program validations (see Section 2.8.2) showed that pilot response time was well within the five seconds allocated by the TCAS logic. There were no adverse comments received from the observers regarding the time taken by a crew in responding to a TCAS Warning.

## CHAPTER FOUR

### DATA ANALYSIS

The effectiveness of an airborne collision avoidance system such as TCAS is dependent both on its technical performance and on its use by a flight crew. The Phase II operational evaluation was designed to provide information on both of these aspects of TCAS: an objective evaluation of the technical performance of the prototype avionics, and a subjective evaluation of the effectiveness of TCAS use by flight crews. This chapter describes the analysis of the data collected during the Phase II evaluation and presents results of the completed analyses in graphic, tabular, and narrative formats.

#### 4.1 TYPES OF DATA

The data collection methods used in the Phase II evaluation were discussed in detail in Chapter Three. The data used in the analyses discussed in this chapter came from two sources: automatically recorded system performance data and qualitative or quantitative data provided by the cockpit observers and flight crews. Both types of data were compiled into data bases maintained on a personal computer to facilitate their review and analysis.

The automatically recorded data were recorded on nine-track magnetic tapes, which were routinely removed from the TCAS aircraft and forwarded to MITRE. At MITRE, the data were copied from the tape cartridge into MITRE's mainframe computer for analysis. MITRE has the capability to recreate any encounter from the recorded data, using its coding of the TCAS logic, to verify proper operation of the prototype avionics. MITRE also has the capability to perform statistical analyses of the encounters, plot the encounter geometry, investigate problems noted by an observer, and produce summary listings of all encounters. Copies of these summary listings were provided to ARINC Research, where selected parameters were entered into a data base hosted on an IBM PC.

In addition to this data base, a second data base was established to permit analysis of information provided by the observers. This data base uses the objective data, such as aircraft location, altitude, intruder type, and sequence of events recorded by an observer. The subjective comments of the observers and pilots were handled manually since they were typically in narrative form.

The types of data and the numbers of observations differ among the data bases. The difference in the number of observations is a result of a request that the flight crews operate TCAS in STANDBY whenever they were untrained, whenever there was no observer on board, and whenever the aircraft was operating in INC or above FL 330. The requirement to operate in STANDBY above FL 330 was a result of the possibility that limitations in the TCAS aircraft's climb performance above FL 340 could induce an unnecessary altitude crossing maneuver (see Table 2-5); it is discussed in detail in References 2 and 3. With the avionics operating in STANDBY, the data recording system remained enabled even though all cockpit displays were inhibited. The TCAS Warning data in these two data bases are routinely compared by MITRE, ARINC Research, and FAA personnel to obtain a detailed understanding of those encounters. Because of the large number of TCAS Cautions experienced during Phase II and a problem with the time-of-day clock (see Section 3.2.5), no attempt has been made to merge the two types of data for the TCAS Cautions. Both types of data were used for the results shown in the subsequent sections of this chapter.

#### 4.2 QUALITY OF DATA

The general quality of both the automatically recorded data and the observer comments was excellent. (The problems related to data collection are detailed in Section 3.2.) The parameters recorded by the tape recorder were sufficient to permit detailed analyses of the avionics performance, and the observer and pilot comments were sufficiently detailed to permit an accurate assessment of the operational efficiency of the avionics and flight crew procedures.

No observed or recorded encounters that resulted in TCAS Cautions or TCAS Warnings against other aircraft were excluded from the analyses conducted by ARINC Research.

The data provided by the observers varied from observer to observer and flight crew to flight crew. In all cases, the objective-data entries on the observer forms (see Appendix C) were completed. The variability was observed in the amount of supporting detail provided on the encounter. Some observers provided very detailed descriptions of an encounter and the crew's handling of the encounter, while others provided only minimal details. The minimal-detail descriptions resulted in the omission of certain data from the data base for several encounters. For example, some observers neglected to note whether or not an intruder was Mode C equipped. This omission affected the statistics of Mode C versus non-Mode C equipped intruders.

During the first four months of the Phase II evaluation, Piedmont was required to include the comment "TCAS EQUIPPED" in the Remarks section of each flight plan for the TCAS aircraft. Discussions with controllers during the initial weeks of the evaluation indicated that this information was not always shown on the flight progress strips during the en route and approach portions of the flight. These discussions also confirmed the observers' observations that the

controllers were not handling the TCAS aircraft any differently than any other aircraft. Based on these discussions, the requirement to identify the aircraft as TCAS equipped was removed. This requirement had no detectable impact on the data collected during the first four months of the evaluation.

#### 4.3 TYPES OF ANALYSIS PERFORMED

The major objectives of the Phase II evaluation were to collect data on a flight crew's use of a collision avoidance system and to assess the impacts such a system has on the workload of a flight crew and ATC. A secondary objective was to provide additional data for a TCAS performance data base. Crews were permitted to use the full capabilities of the TCAS system and respond to TCAS Warnings generated by the system.

Data for each of the 48 encounters that resulted in a TCAS Warning were analyzed in detail to develop an understanding of the system's performance during the encounter and the crew's response to it. Of these 48 encounters, 37 occurred while an observer was on board and TCAS was being used by the crew. The TCAS Warnings are summarized in Appendix D.

The data from the TCAS Cautions were also analyzed, but not to the same level as the Warnings. The Cautions were generally reviewed in detail only when a quick review of the data or an observer's report indicated the existence of a problem.

Individual case analyses, as indicated above, provided an understanding of the sequence of events during individual encounters. The data accumulated in both data bases permit a better characterization of a "typical" encounter and the development of distributions for various parameters, such as the following:

- Range and bearing of intruder at first advisory
- Relative altitude of intruder at first advisory
- Range at closest point of approach (CPA)
- Distribution of vertical separation at CPA
- Distribution of own-aircraft altitude at first advisory
- Distribution of times prior to CPA when advisories were issued
- Duration of advisories
- Advisories by type of aircraft (when observed)
- Distribution of the time-of-day when advisories occurred
- Distribution of TCAS Warnings by type
- Frequency of visual acquisition after advisories
- Advisory frequency
- Geographic distribution of advisory by location

#### 4.4 QUANTITATIVE RESULTS

The Phase II operational evaluation was initiated on March 18, 1987. This report presents the data and results from the initiation of the Phase II through its completion on January 29, 1988. During this period, TCAS was used by flight crews for 828 flight hours and 714 flight



segments. The TCAS aircraft flew for a total of 1515 hours with the TCAS avionics on board and available for use by the crews. (The reasons for the difference in the total flight hours and the TCAS-use hours are discussed in Section 3.2.) During this time, there were 48 TCAS Warnings, 37 observed TCAS Warnings, 723 automatically recorded TCAS Cautions, and 471 observed TCAS Cautions. The observed TCAS Cautions and Warnings occurred while a TCAS observer was in the cockpit.

No significant hardware or software problems were detected during the Phase II evaluation that required interrupting the evaluation. There were several hardware failures that required the avionics to be returned to Dalmo Victor for repair. The details of these repair activities are discussed in Appendix E. In addition to the hardware problems, several avionics and operational procedure anomalies were detected, and these should be corrected in future TCAS installations. These anomalies are discussed in Chapter Six.

#### 4.4.1 Advisory Rates

In calculating the frequency of both TCAS Cautions and Warnings, the data contained in the data base developed from the observer comments were used. This is the only source for which an accurate log of flight hours was maintained.

Thirty-seven observed encounters generated one or more TCAS Warnings each. A TCAS Warning was issued (on the average) once every 22.4 hours. This advisory rate represents an 66 percent increase over the resolution advisory rate observed during the Phase I evaluation in 1981-1982. The change may be attributed in part to an increase in the number of total operations in the NAS since the Phase I evaluation, the growth of airline hubs at various airports, and different scheduling of aircraft by airlines.

No negative comments were received from either the flight crews or the observers regarding the frequency of the TCAS Warnings. Three of the TCAS Warnings were issued just as the range between the TCAS aircraft and the intruder began to diverge, and these were considered unnecessary by the observer and the data analysts, but not by the flight crew. (See Section 6.4 for a detailed discussion of these advisories.)

The incidence of TCAS Cautions was much higher. A total of 471 TCAS Cautions were observed, for a rate of one TCAS Caution per 1.76 flight hours. This represents an increase of 291 percent over the rate observed during the Phase I evaluation. While the reasons cited above for the increase in the rate of TCAS Warnings are also applicable to TCAS Cautions, a change in the design of the TCAS surveillance that permits the tracking of non-altitude reporting aircraft is responsible for most of the increase. During the Phase II evaluation, 48 percent of the TCAS Cautions were issued against non-Mode C intruders. (TCAS Cautions are issued against non-Mode C traffic only when the TCAS aircraft is below 15,500 feet MSL.)

The total advisory counts and advisory rates are summarized in Table 4-1.

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Table 4-1. Advisory Counts and Rates

---

<u>Advisory</u>	<u>Count or Rate</u>
TCAS Cautions	
Observed	471
Recorded	723
Non-Mode C	48%
TCAS Caution Frequency	1 per 1.76 flight hours 1 per 1.52 flight segments
TCAS Warnings	
Total	48
Observed	37
TCAS Warning Frequency	1 per 22.4 flight hours 1 per 19.3 flight segments

---

#### 4.4.2 Types of Intruder Aircraft

One of the items of information recorded by the cockpit observers was the type of aircraft causing the TCAS advisory. This information was obtained from the visual acquisition of the intruder aircraft or from traffic advisories issued by ATC. The distribution of intruders by type is shown in Figure 4-1.

An operational problem with TCAS was detected while the TCAS aircraft was operating to and from Norfolk, Virginia. Numerous non-Mode C intruders were simultaneously displayed to the crew as "No Bearing" targets. Investigations by the FAA and ARINC Research determined that many U.S. Navy ships are equipped with transponder-like devices that respond to TCAS interrogations. (This problem is discussed in detail in Section 6.1.) The traffic advisories issued against these ships are not included in the data base obtained from the cockpit observers.

#### 4.4.3 Altitude at Time of Advisory

Approximately 70 percent of the Cautions and 60 percent of the Warnings occurred while the TCAS aircraft was operating below 10,000 feet MSL. Of the non-Mode C intruders, 80 percent occurred while the TCAS aircraft was below 10,000 feet MSL. The elevations of the airports served during this evaluation (see Section 2.2) are typically lower than 1,000 feet MSL. The distribution of own-aircraft altitudes at the times of the advisories is shown in Figure 4-2.

The distribution shown in Figure 4-2 indicates that 85 TCAS Cautions occurred while the TCAS aircraft was operating below 1,000 feet MSL.

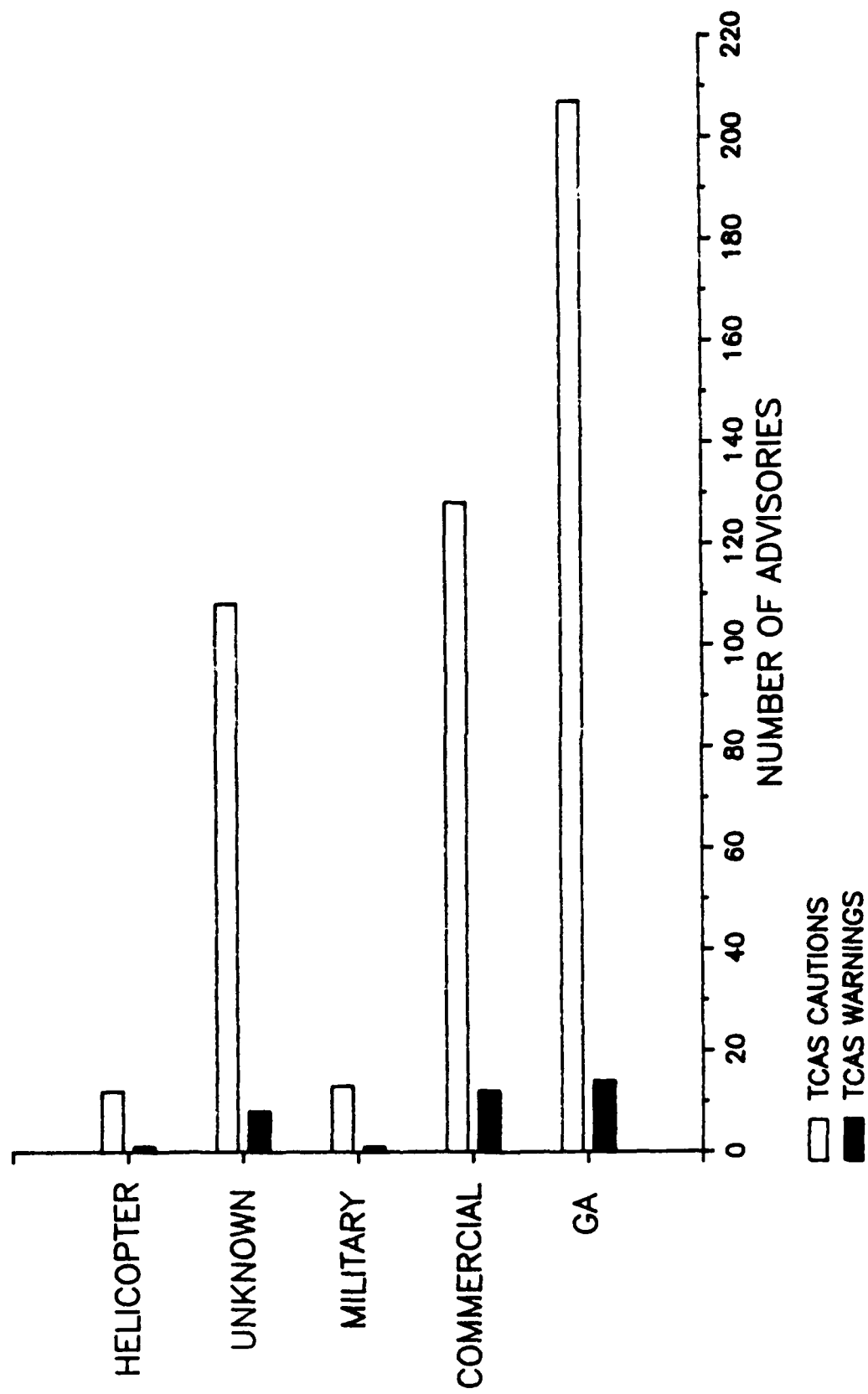


FIGURE 4-1  
DISTRIBUTION OF ADVISORIES BY INTRUDER TYPE

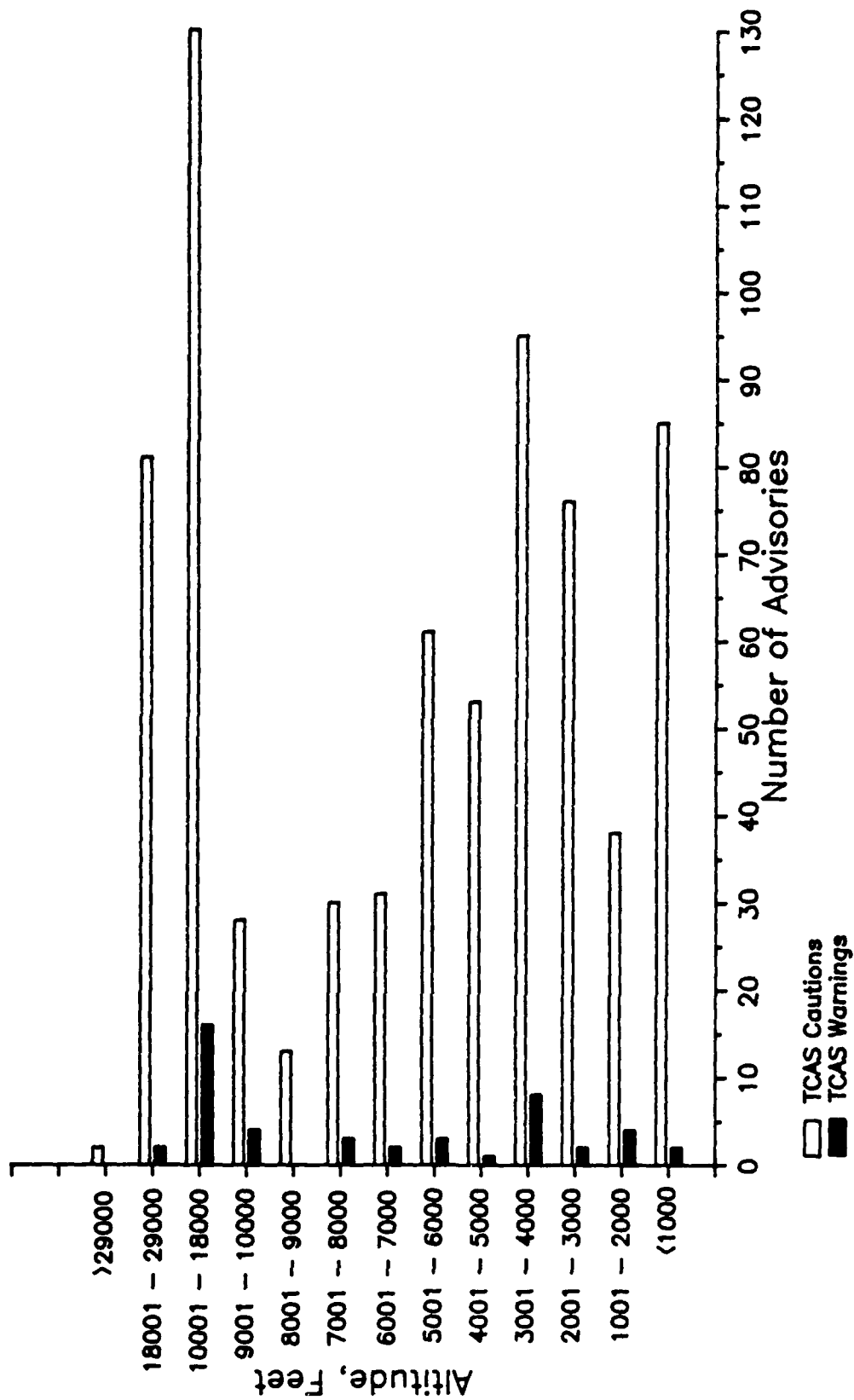


FIGURE 4-2  
 OWN ALTITUDE WHEN ADVISORY IS ISSUED

After the Phase I evaluation, logic was added to prevent the display of aircraft on the ground. This modification was proven to be effective against aircraft equipped with altitude reporting transponders. However, non-altitude reporting aircraft do not provide sufficient inputs into the TCAS logic to enable TCAS to declare that an aircraft is on the ground. As a result, TCAS will issue a TCAS Caution against non-altitude reporting aircraft whose transponders are turned on while they are taxiing. (This problem is discussed in detail in Section 6.2.) Figure 4-3 shows the distribution of own-aircraft altitude when non-Mode C and Mode C TCAS Cautions are issued. Since the TCAS Aircraft-On-Ground logic operates only when the TCAS aircraft is below 2,500 feet AGL, Figure 4-3 shows the altitude distribution from zero to 2,500 feet.

#### 4.4.4 Vertical Separation at Time of Advisory

Figure 4-4 presents the distribution of the vertical separation of the TCAS and intruder aircraft at the time of the initial advisory. It shows the separation at the time a Caution is issued, since TCAS Warnings are almost always preceded by a TCAS Caution. Because altitude information on a non-altitude reporting intruder is not available, there is no way to assess its vertical separation from the TCAS aircraft at the time a TCAS Caution is issued.

For a mix of aircraft operating under visual flight rules (VFR) and instrument flight rules (IFR), the normal vertical separation is 500 feet. The minimum vertical separation for two aircraft operating IFR is 1,000 feet.\* These minimums typically apply to aircraft in level flight, and horizontal separation is used as a primary means of separating climbing and descending aircraft. These separations can be violated in the terminal area when one aircraft has a second aircraft in sight and a crew has accepted the responsibility for maintaining visual separation. These types of encounters may account for the 17 percent of the encounters with less than  $\pm 500$  feet of separation when the Caution was issued.

The recorded data show that when the vertical separation at the time of advisory is less than 500 feet, the TCAS aircraft is below 4,000 feet MSL in 81 percent of the encounters, which indicates that the encounter occurs near an airport, where visual separation is often used in visual meteorological conditions (VMC). Fewer than eight percent of the Cautions were issued against aircraft with more than  $\pm 2,000$  feet of separation from the TCAS aircraft, and these advisories generally occurred when the TCAS aircraft was climbing or descending at a high rate. More than 83 percent of the TCAS Cautions were issued against aircraft within 1,500 feet of the TCAS aircraft, and 55 percent of the Cautions were issued against aircraft within 1,000 feet of the TCAS aircraft. This indicates that the present TCAS logic seldom generates unnecessary TCAS Cautions. Because of the different altitude sensitivities in the avionics and the effects of climbing or descending aircraft, Cautions issued with these altitude separations are acceptable.

\*Federal Aviation Regulations, Parts 91.109 and 91.121.

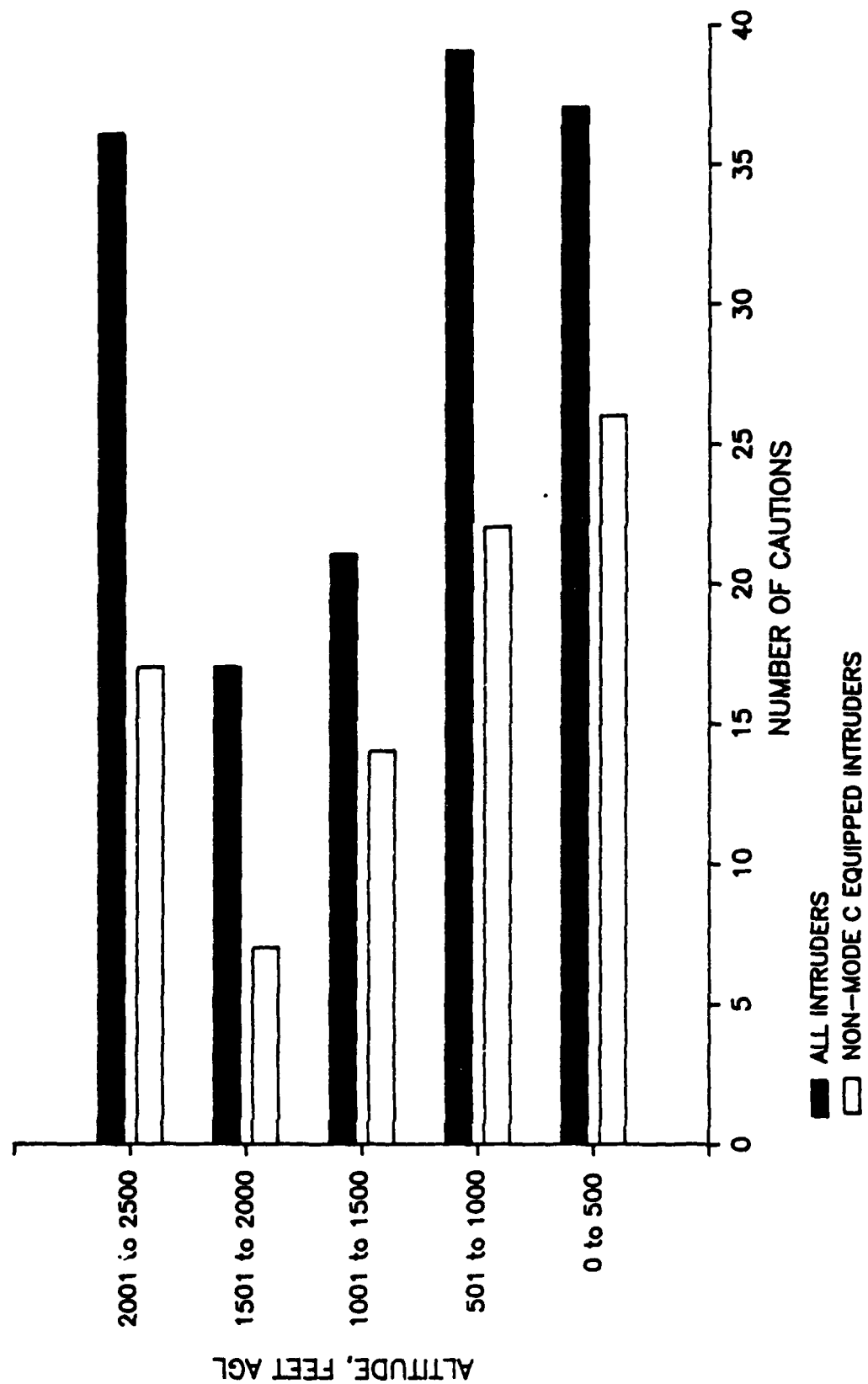


FIGURE 4-3  
TCAS AIRCRAFT ALTITUDE WHEN CAUTION IS ISSUED

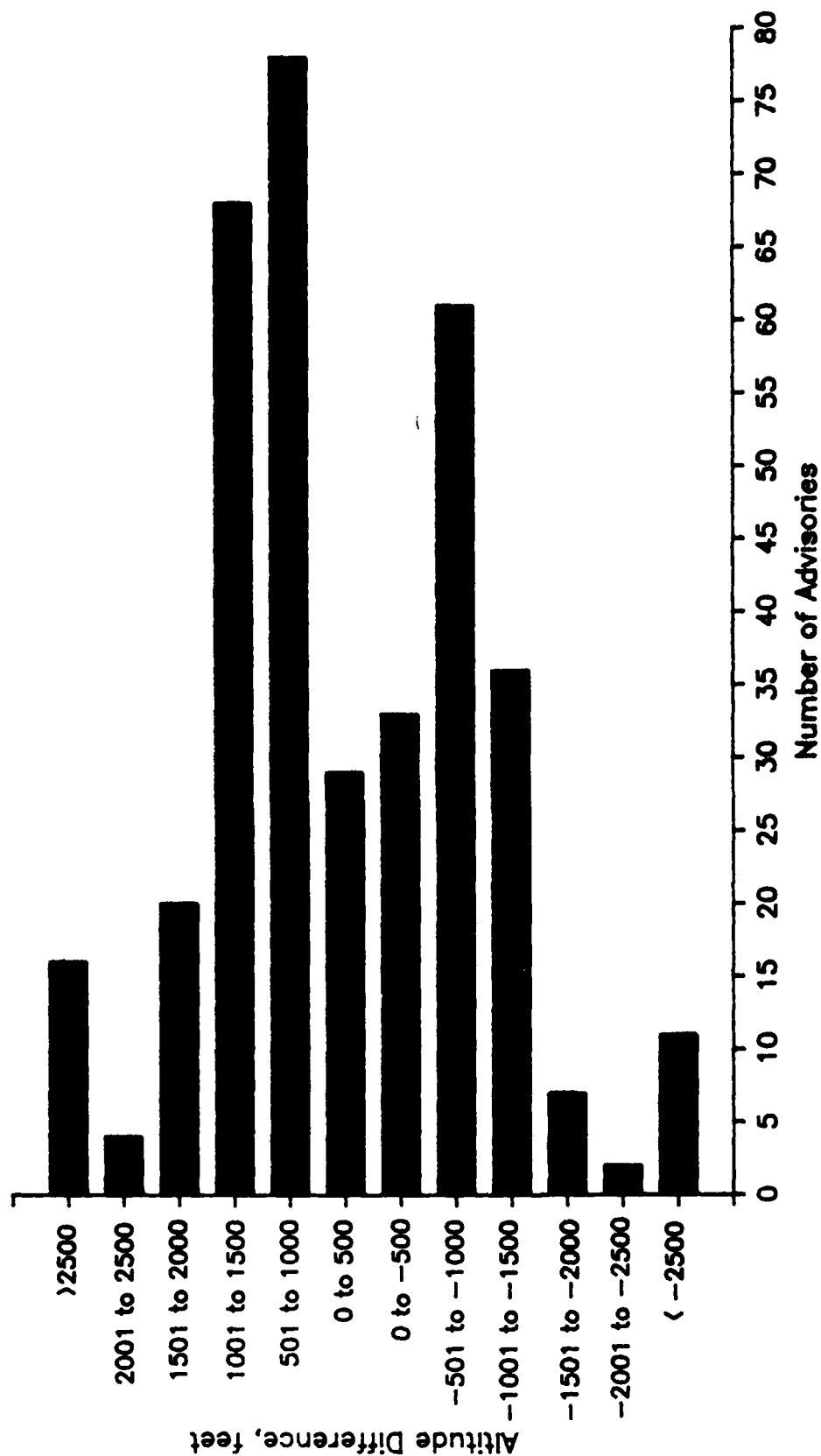


FIGURE 4-4

VERTICAL SEPARATION WHEN CAUTION IS ISSUED

#### 4.4.5 Range at First Advisory

The other criterion for assessing the utility of TCAS is the range between the TCAS-equipped and intruder aircraft when an advisory is issued. Although TCAS issues advisories based on time and not distance, its sensitivity must be such that unnecessary advisories are not issued. Figure 4-5 illustrates the horizontal separation between the TCAS aircraft and the intruder aircraft when a TCAS Caution was issued. It shows that 84 percent of the Cautions occurred at a range of 5 nm or less and 61 percent occurred at a range less than 3 nm. The advisories issued against aircraft at ranges greater than 5 nm generally occurred at altitudes above 10,000 feet MSL where both the test and intruder aircraft were flying at high speeds.

During the review of these range data, the number of advisories occurring with initial ranges less than 3 miles (61 percent) were examined further to ensure that the avionics were working properly. Figure 4-6 was prepared to show the range between the TCAS aircraft and non-altitude reporting intruders. These data indicate that 60 percent of the Cautions issued when the range between the TCAS aircraft and intruder aircraft was less than 3 nm were against non-Mode C equipped intruders. Further, 63 percent of the Cautions issued when the range was less than 1 nm were against non-Mode C equipped aircraft. This was expected because Cautions against non-Mode C aircraft are not issued until 25 to 30 seconds prior to CPA, versus the 40 to 45 seconds used for altitude reporting aircraft. This reduced sensitivity was selected to minimize the number of non-Mode C Cautions displayed to the crew, since altitude information is not available to determine the vertical separation with the intruder.

The Cautions issued against altitude reporting intruders at low range occurred either (1) when the intruder maintained adequate vertical separation until the range between the aircraft was small or (2) when the TCAS aircraft was slowly overtaking the intruder aircraft. The first case occurs when the TCAS aircraft or the intruder aircraft initiates a climb or descent at close range and the vertical rate results in meeting the altitude criterion for issuing a TCAS Caution after the range criterion has been satisfied. The second case occurs when the TCAS aircraft is overtaking the intruder and the closure rate is low. This typically occurs when the intruder is a jet aircraft, both aircraft are on parallel approaches, and the TCAS aircraft's speed is 10 to 15 knots higher than the intruder's speed.

#### 4.4.6 Vertical Separation at CPA

The recorded data were also analyzed to assess the vertical separation at CPA. Since CPA represents the closest horizontal distance between the aircraft during an encounter, the vertical separation provided by TCAS at CPA is an indication of the effectiveness of TCAS. Figure 4-7 shows the range of altitude differences at CPA for all TCAS Cautions and TCAS Warnings. The distribution of the altitude differences at CPA is shown in Table 4-2 for both TCAS Cautions and Warnings.



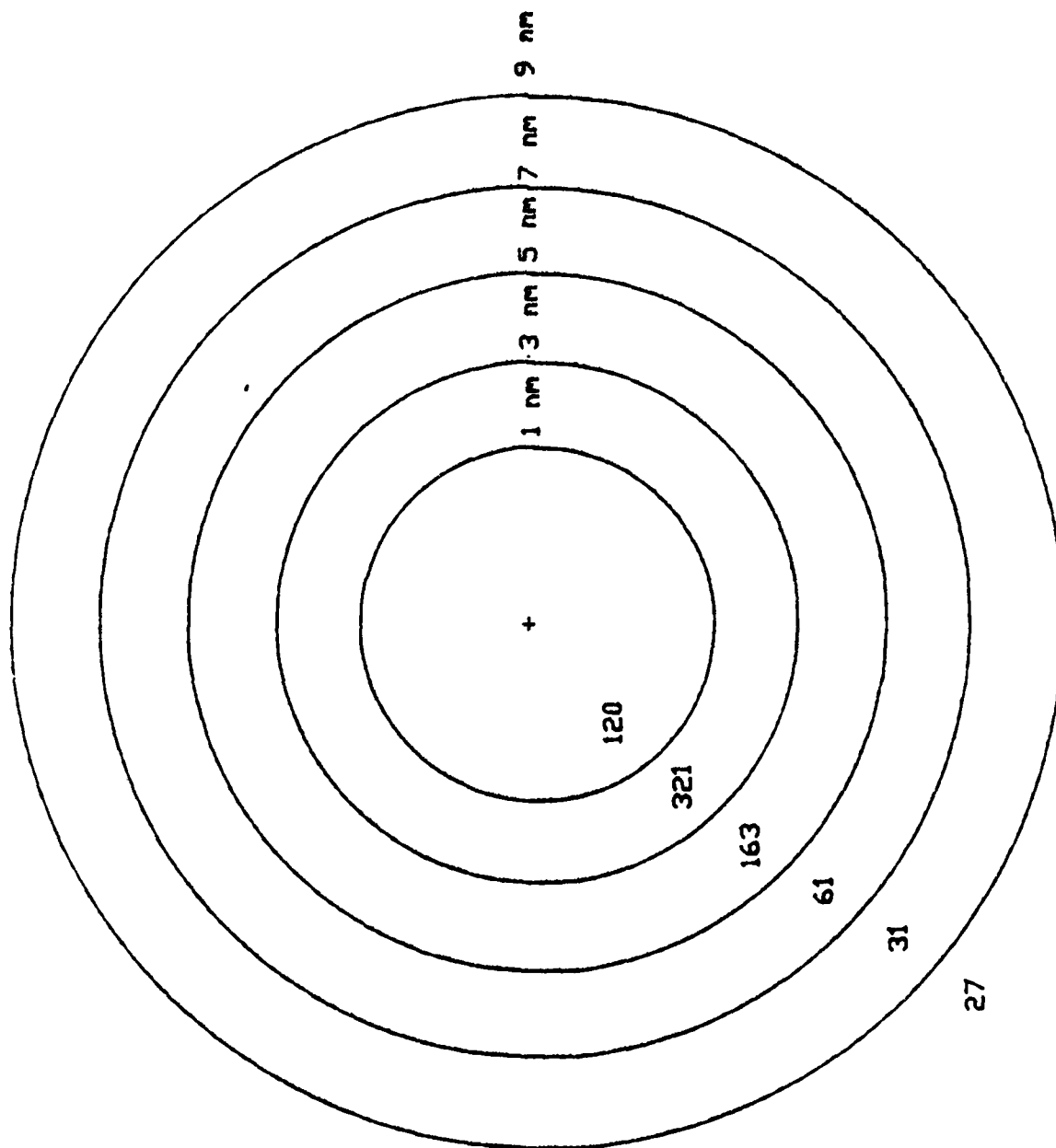


FIGURE 4-5

INTRUDER'S RANGE WHEN TCAS CAUTION IS ISSUED (ALL CAUTIONS)

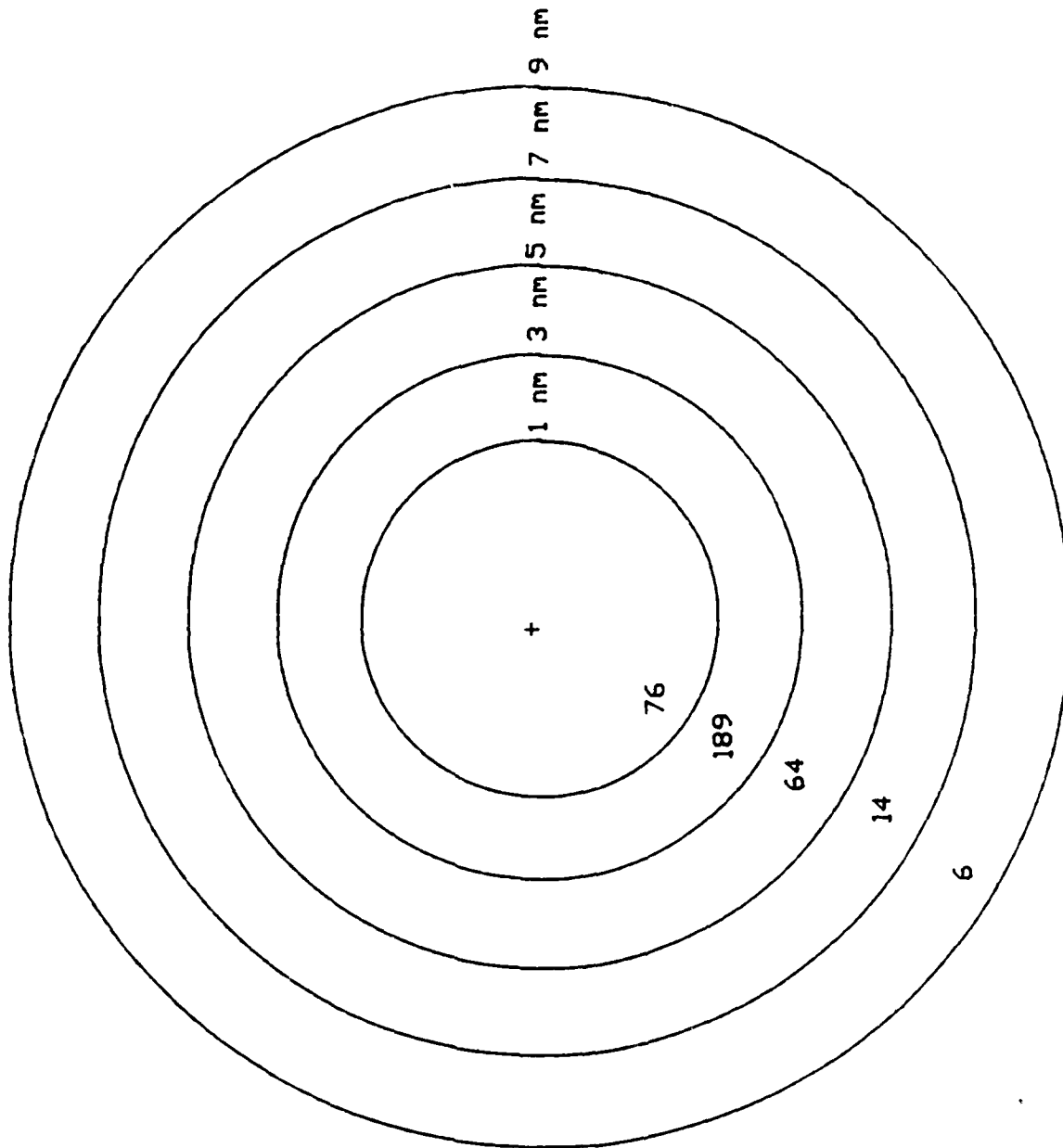


FIGURE 4-6

NON-ALTITUDE REPORTING INTRUDER'S RANGE WHEN TCAS CAUTION IS ISSUED

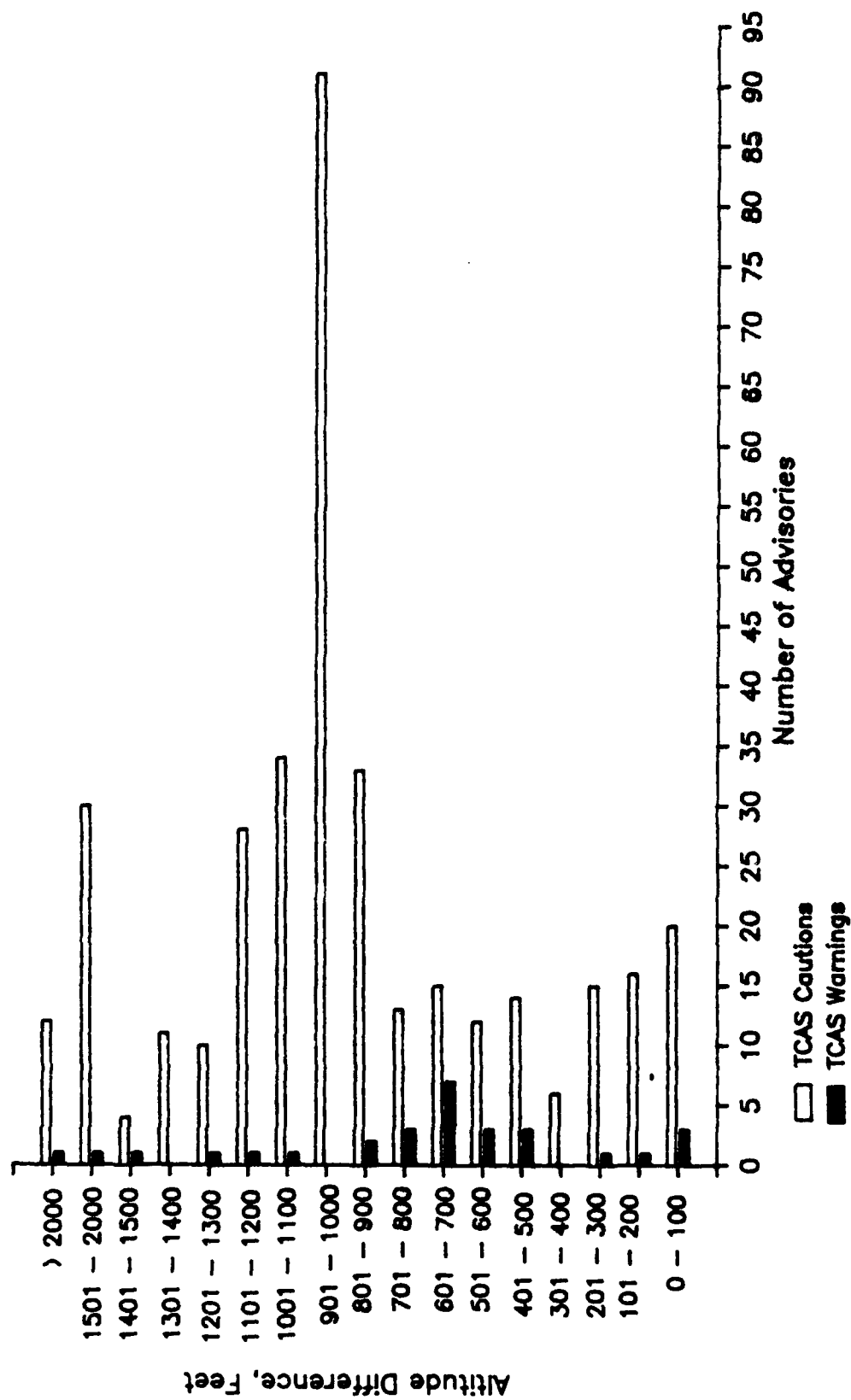


FIGURE 4-7

ALTITUDE DIFFERENCE AT CPA

Table 4-2. Distribution of Altitude Separation at CPA

Altitude Difference	Frequency (Percent)	
	TCAS Cautions	TCAS Warnings
0 to 200 feet	10	14
201 to 400 feet	6	3
401 to 600 feet	7	21
601 to 800 feet	8	34
801 to 1,000 feet	34	7
1,001 to 1,200 feet	17	4
1,201 to 1,400 feet	6	7
1,401 to 1,600 feet	3	3
1,601 to 1,800 feet	3	4
1,801 to 2,000 feet	3	0
> 2,000 feet	3	3

The small number of encounters that have separations greater than 1,200 feet at CPA generally occur when the TCAS aircraft or intruder aircraft is climbing or descending. The separations of less than 500 feet were reviewed in detail, and the data showed that these encounters typically occur at low altitudes, indicating that the aircraft are probably operating near an airport and visual separation is being used. The observer data indicate that these types of Cautions generally occur when simultaneous visual approaches are in use at an airport. The recorded data and observer data suggest that the system is not issuing many unnecessary Cautions and that adequate vertical separation is being provided by TCAS.

The distribution of altitude separation at CPA for encounters resulting in TCAS Warnings shows a peak between 600 to 800 feet. This peak is primarily the result of Warnings issued while the TCAS aircraft is below 10,000 feet MSL, where TCAS is designed to provide 750 feet of separation. The small vertical separations shown in the distribution occurred either during TCAS aircraft operations in a terminal area when the crew had the intruder in sight and elected not to respond to the TCAS Warning or during simultaneous parallel-approach operations.

#### 4.4.7 Range at CPA

Figure 4-8 illustrates the range at CPA for all TCAS Cautions. It shows that 84 percent of the intruders passed within 3 nm of the TCAS aircraft and 37 percent passed within 1 nm. This is further indication that TCAS is not issuing many unnecessary advisories and that a majority of the intruders causing advisories continued toward the TCAS aircraft after the advisory was issued. Figure 4-9 shows the range at CPA for

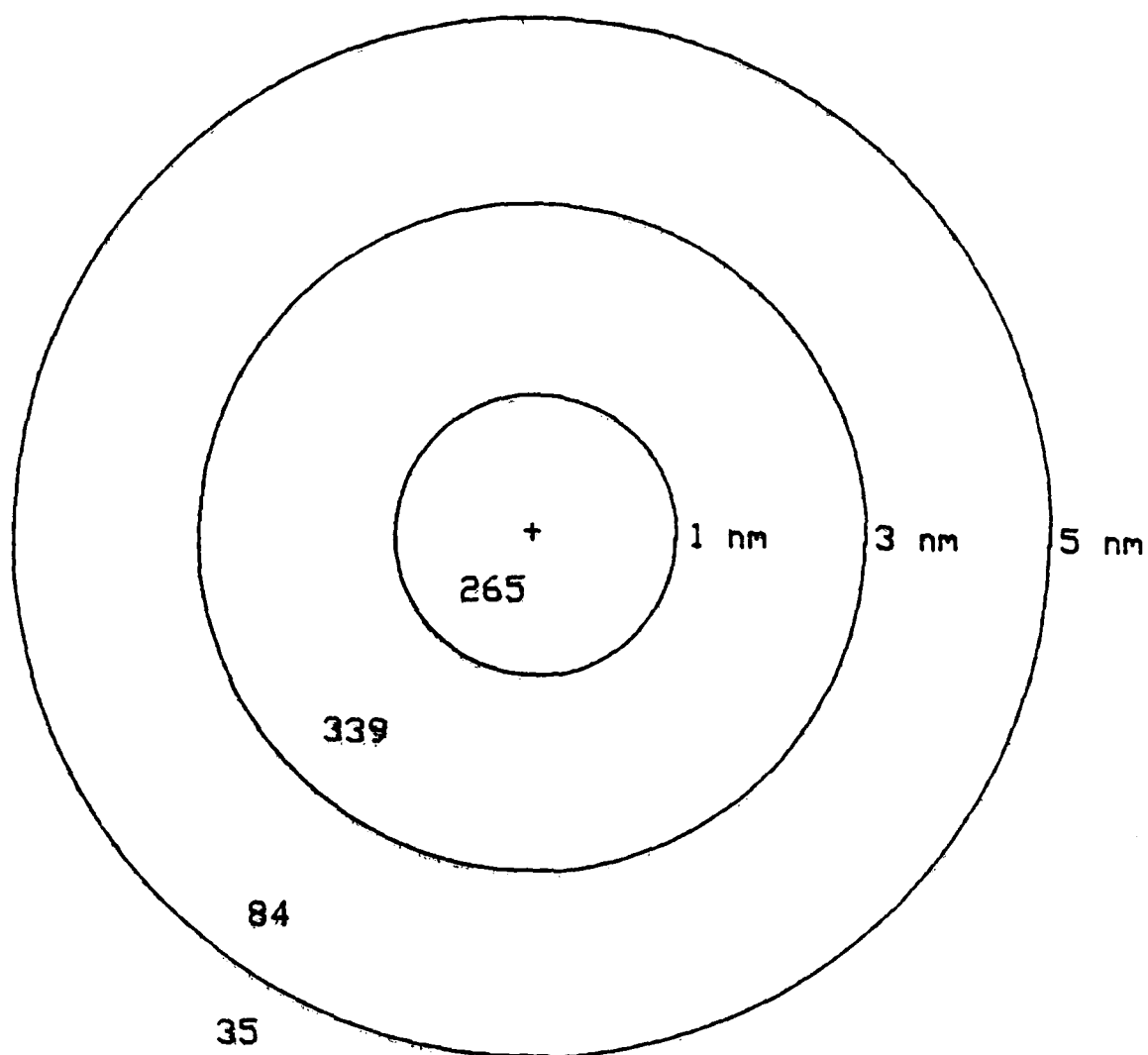


FIGURE 4-8  
INTRUDER'S RANGE AT CPA (ALL CAUTIONS)

non-Mode C equipped intruders and indicates that 58 percent of the intruders coming within 1 nm of the TCAS aircraft are not equipped with Mode C. Because of the lack of altitude information, there is no way to measure the vertical separation between these intruders and the TCAS aircraft. As was the case for the range at first advisory (see Section 4.4.5), the altitude reporting intruders passing close to the TCAS aircraft either had adequate vertical separation until the range between the two aircraft was small or the intruder and TCAS aircraft passed each other while on parallel approaches while maintaining visual separation.

Figure 4-10 illustrates the range at CPA for those encounters causing TCAS Warnings. The data show that 97 percent of the TCAS Warnings were resolved with the intruder passing within 3 nm of the TCAS aircraft. This range, coupled with the altitude separation at CPA (see Section 4.4.6), indicates that the parameters used by TCAS to issue TCAS Warnings are adequate and that sufficient separation is being provided without the issuance of unnecessary advisories.

#### 4.4.8 Relative Bearing of Threat Aircraft at Time of Advisory

The bearing data recorded during the operational evaluation confirmed the intuitive expectation (and Phase I results) that the majority of the conflicts would develop within a bearing of  $\pm 90$  degrees, from the TCAS aircraft. Figure 4-11 shows the frequency of both TCAS Cautions and TCAS Warnings by relative bearing octant. More than 94 percent of the TCAS Cautions were generated by an intruder aircraft within  $\pm 90$  degrees, and 74 percent of the TCAS Cautions were generated by aircraft within  $\pm 45$  degrees. With the exception of one Warning, all of the TCAS Warnings were caused by intruder aircraft with an initial relative bearing of  $\pm 90$  degrees. Seventy-seven percent of the TCAS Warnings occurred with an initial bearing of  $\pm 45$  degrees. The one Warning with a relative bearing of  $-95$  degrees was caused by the intruder turning towards the TCAS aircraft just as the two aircraft began to diverge in range.

The bearing data for the non-Mode C intruders are similar to the data for all TCAS Cautions. As shown in Figure 4-12, 94 percent of the non-Mode C intruders had an initial bearing of  $\pm 90$  degrees and 74 percent had an initial bearing of  $\pm 45$  degrees.

The bearing data observed during the evaluation were stable, and the visual sighting of an intruder confirmed that the bearing determination algorithms are correctly calculating and displaying the approximate bearing. No bearing jumps or incorrectly displayed bearings were reported by the observers. The directional antenna mounted on the TCAS aircraft functioned properly, and the antenna patterns were approximately the same as in the factory testing and FAA Technical Center testing. This is a qualitative assessment based on observer reports and on the fact that the No Bearing display was generally annunciated with a low range value. The No Bearing display typically resulted in the crew or observer visually acquiring the traffic directly below, or nearly directly below, the TCAS aircraft. These observations also provide an indication that the omnidirectional antenna functioned properly during the evaluation.

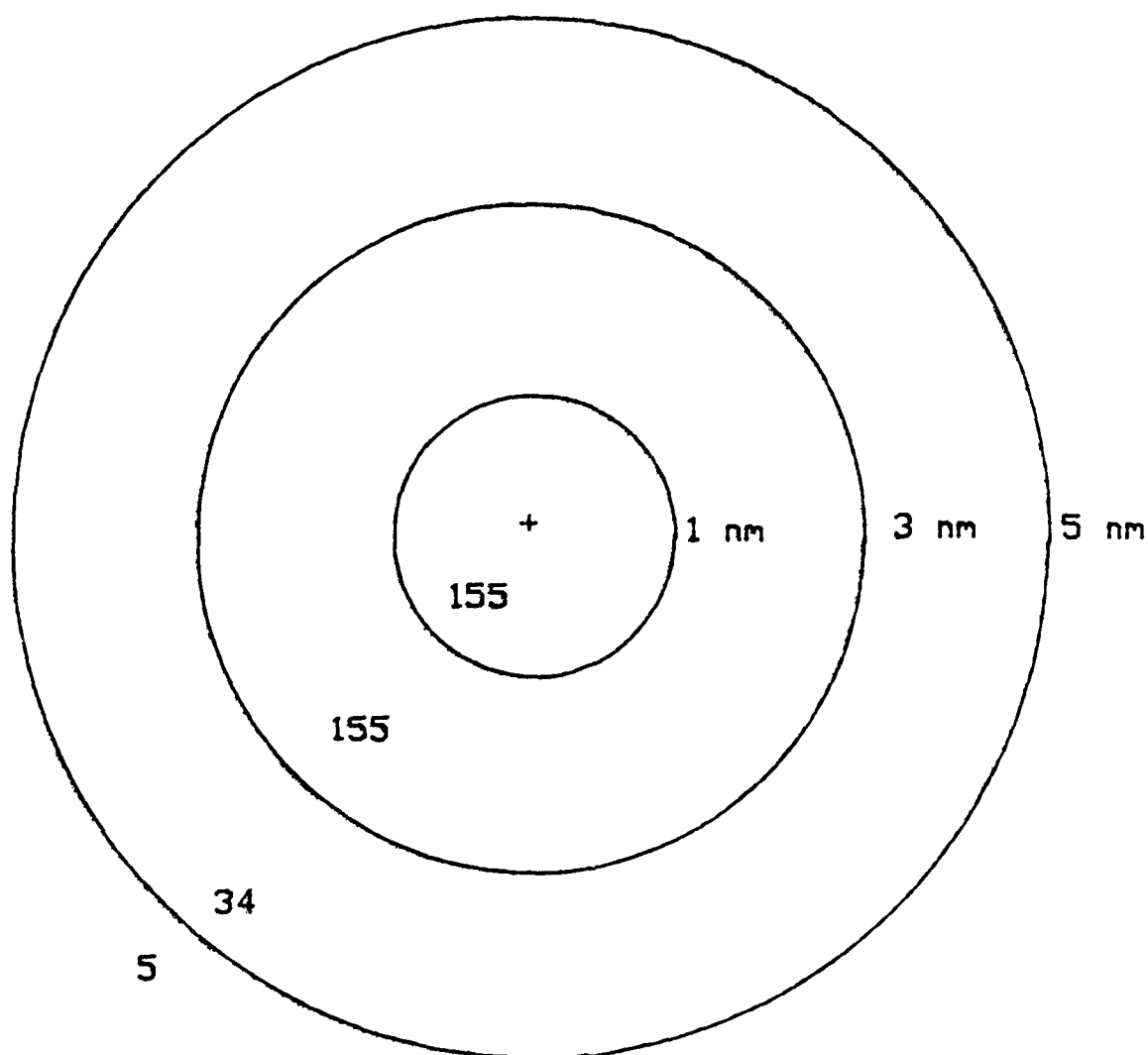


FIGURE 4-9

INTRUDER'S RANGE AT CPA (NON-ALTITUDE REPORTING INTRUDERS)

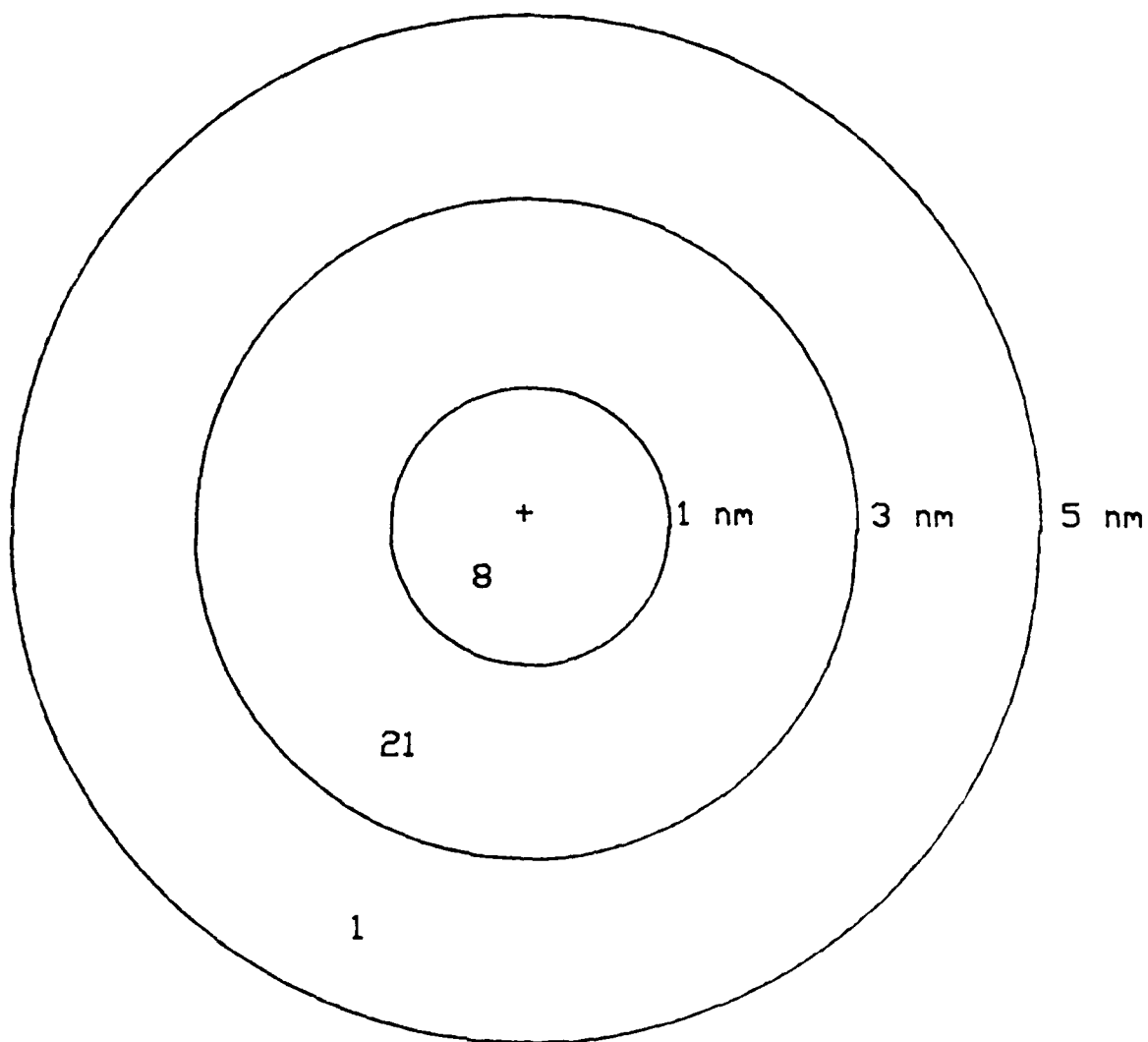


FIGURE 4-10  
RANGE AT CPA FOR TCAS WARNING ENCOUNTERS



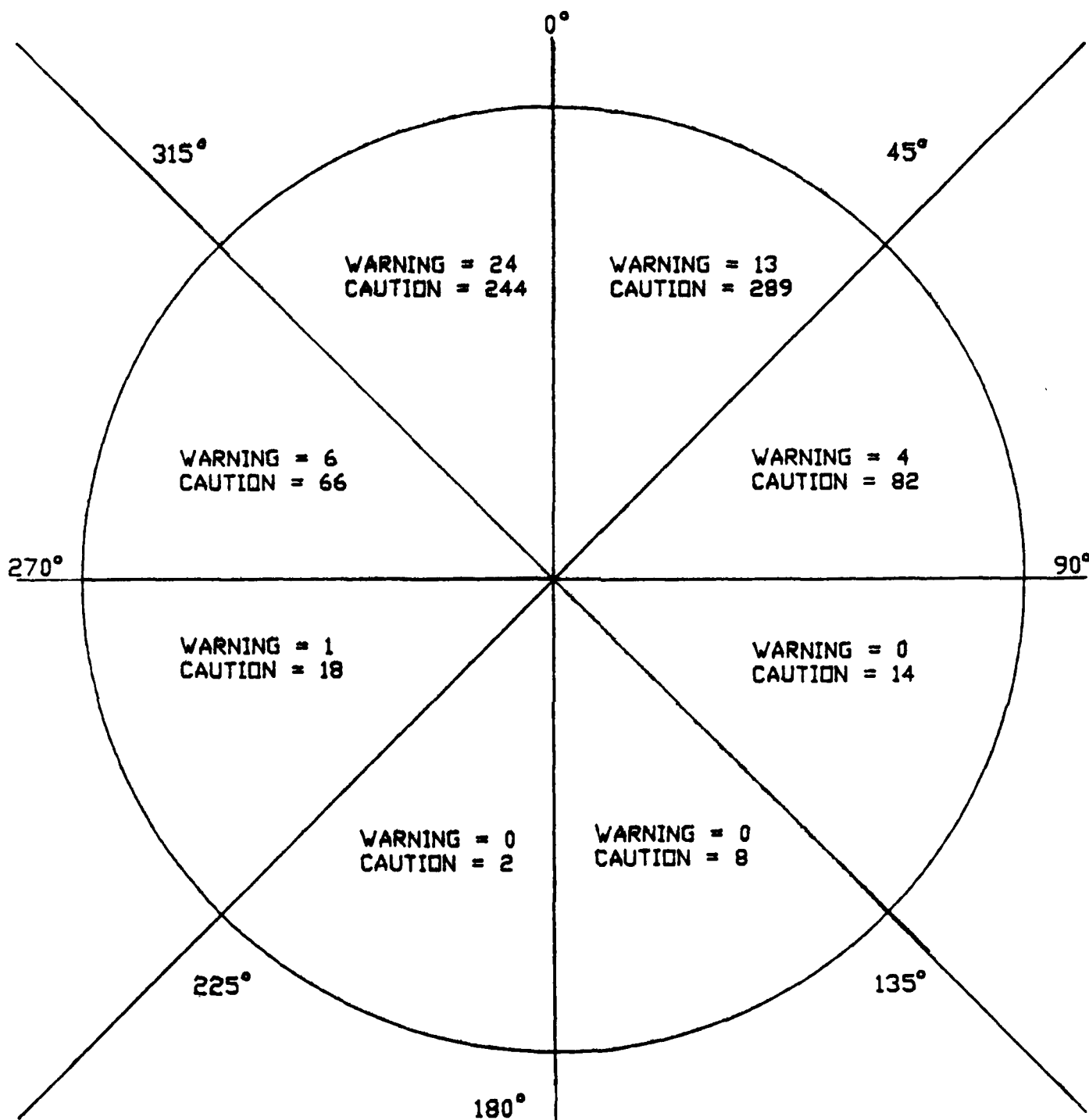


FIGURE 4-11

ADVISORIES BY INITIAL BEARING (ALL INTRUDERS)

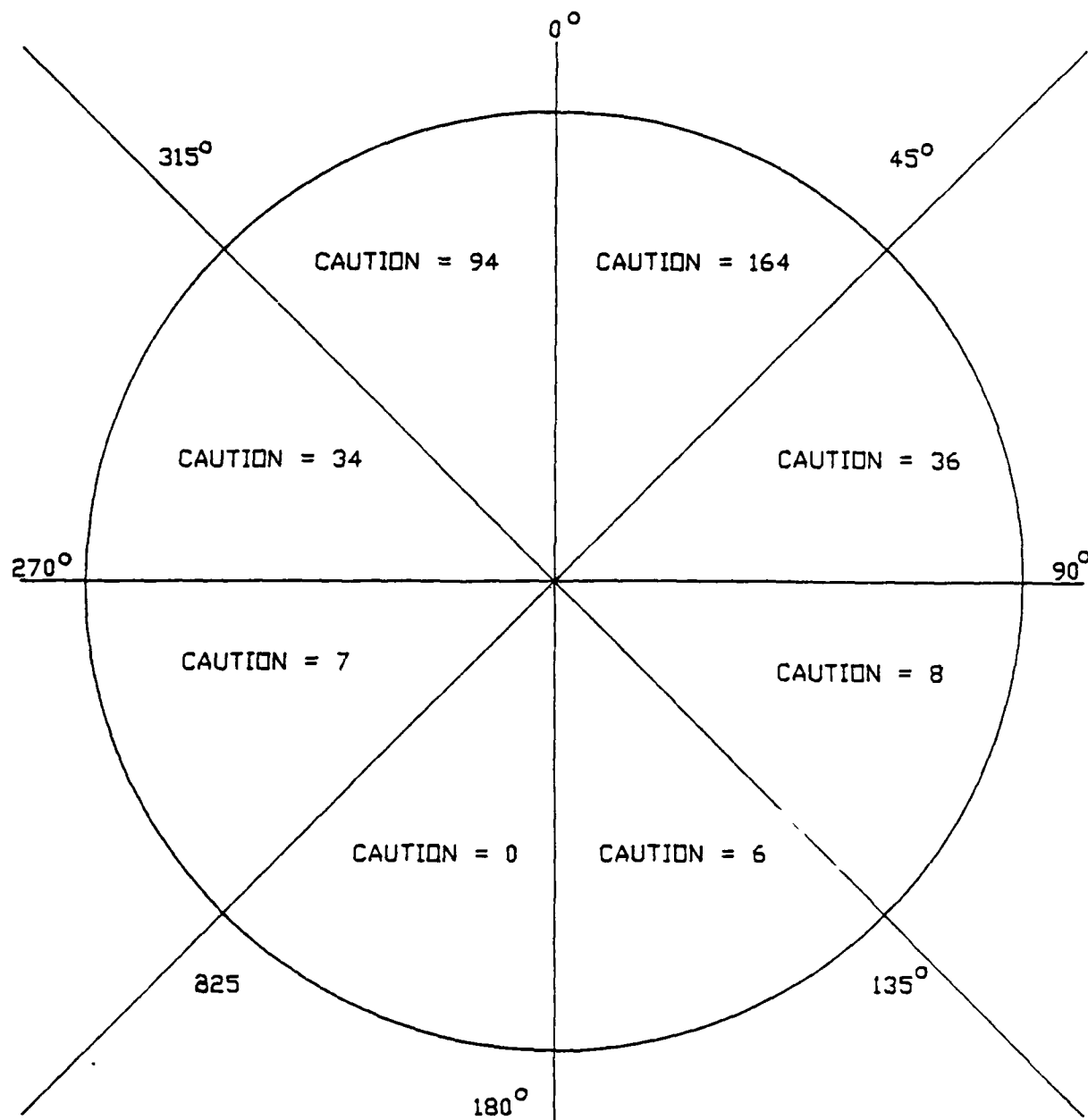


FIGURE 4-12

ADVISORIES BY INITIAL BEARING (NON-MODE C INTRUDERS)

#### 4.4.9 Types of TCAS Warnings

Forty-eight encounters that resulted in TCAS Warnings were observed or recorded during the Phase II evaluation. These 48 Warnings resulted in the issuance of 57 different TCAS warning advisories to the flight crews. The multiple advisories indicate either a strengthening or weakening of the initial TCAS Warning, because either the crew elected not to respond to the initial advisory or the crew's response provided adequate separation. Thirty-four, or 71 percent, of the initial advisories were up-sense advisories; 14, or 29 percent, of the advisories were down-sense advisories. These data are summarized in Figure 4-13.

#### 4.4.10 Effect of TCAS Warnings on Flight Path

The effect of a TCAS Warning on the TCAS aircraft's flight path is dependent on the type of advisory and the flight crew actions necessary to comply with the advisory. TCAS Warnings can be categorized in two ways:

- Corrective Advisory - a TCAS Warning that requires a change in the aircraft's current vertical rate -- for example, either a CLIMB advisory while the aircraft is in level flight or descending or a DO NOT DESCEND advisory while it is descending.
- Preventive Advisory - a TCAS Warning that is not corrective -- for example, a DO NOT CLIMB advisory while the aircraft is in level flight.

The classification of a TCAS Warning as either corrective or preventive is dependent on the vertical rate of the TCAS aircraft when the advisory is first issued.

In the 48 encounters, there were 39 corrective and 9 preventive advisories. Thirty-four of the 39 corrective advisories occurred while the TCAS aircraft was either climbing or descending. These advisories resulted in the establishment of a lower climb or descent rate or in the momentary leveling of the aircraft, unless the crew had other information that permitted them not to follow the TCAS-recommended maneuver. Unless ATC requested a crew to expedite a climb or descent, these responses generally had little or no impact on ATC. No problems were reported by either ATC or the flight crew after a crew responded to these types of advisories.

Five of the 39 corrective advisories occurred while the TCAS aircraft was in level flight. In two encounters, the crew followed the advisory and deviated from an ATC-assigned altitude. In one encounter, in the New York terminal area, the TCAS aircraft climbed approximately 200 feet from the assigned altitude. In the other, north of Orlando, Florida, the aircraft descended 300 feet from the assigned altitude. In this encounter, the DESCEND advisory occurred after the crew failed to respond to a LIMIT VERTICAL RATE - DO NOT CLIMB Warning that occurred when the TCAS aircraft was approximately 500 feet below its assigned

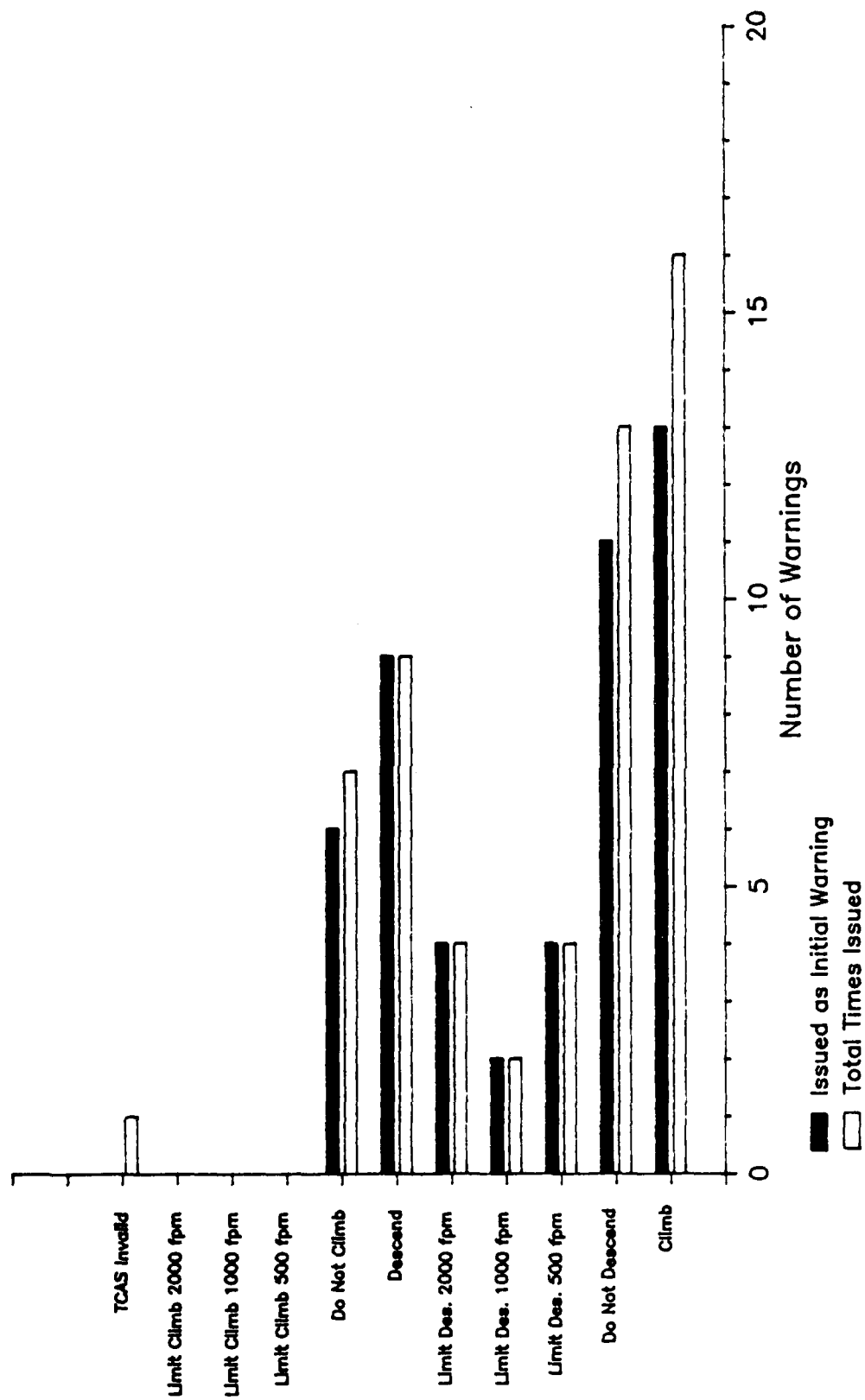


FIGURE 4-13

TCAS WARNING FREQUENCY

altitude. The observer did not mention the DO NOT CLIMB advisory in his report so it is impossible to determine why this advisory was not followed. If the DO NOT CLIMB advisory had been followed, the DESCEND advisory, and the subsequent movement from the assigned altitude would have been unnecessary. In both of these encounters, the intruder aircraft was not visually acquired by the crew and there were no reported impacts to ATC. In the other three encounters, the intruder was visually acquired before the TCAS Warning was issued, and the crew elected not to follow the advisory.

Thirty-seven of the TCAS Warnings were witnessed by a TCAS observer, and 30 of these were corrective advisories. The flight crews responded to 15 of them. In the other 15 observed encounters which resulted in a corrective advisory, 13 were not followed because the crew had the intruder in sight or had other information from ATC on the intruder and used this information to resolve the situation. In two cases, the intruder was not in sight and the crew was not permitted to respond to the advisory because of an FAA requirement during the first 400 hours of TCAS operation to visually acquire the intruder before following a TCAS advisory.

#### 4.4.11 Duration of Advisories

The automatically recorded data provided information on how long a TCAS Caution and a TCAS Warning were displayed to the crews. Figure 4-14 shows the durations of the TCAS Cautions issued against altitude reporting intruders. Forty-seven TCAS Cautions with durations of less than eight seconds were issued against altitude reporting intruders. The TCAS II Minimum Operational Performance Standards (MOPS) require that all Cautions remain displayed for at least eight seconds. The details of this problem are discussed in Section 6.2. Fourteen percent of the Cautions had durations longer than 45 seconds, indicating that the intruder and TCAS aircraft were on nearly parallel courses and the change in range (range rate) was very small.

Figure 4-15 presents the distribution of Caution durations for Cautions issued against non-Mode C intruders. The distribution shows that 41 percent of these Cautions had durations shorter than 10 seconds and 13 percent had durations shorter than 5 seconds. These short duration Cautions presented a problem to both flight crews and observers, since the display was often removed before a crew had a chance to interpret it. (This problem is discussed further in section 6.2.) Ninety percent of the Cautions against non-Mode C intruders had durations shorter than 30 seconds. This was expected since Cautions issued against non-Mode C equipped intruders are not displayed until the TCAS Warning tau criterion is met.

Figure 4-16 presents the distribution of durations for the TCAS Warnings. The distribution shows that 53 percent of the recorded Warnings had durations of 15 seconds or shorter. These are the Warnings in which only one advisory was displayed, the initial vertical separation was just below the Warning threshold, or the crew responded to the displayed advisory. The remaining Warnings generally represent those

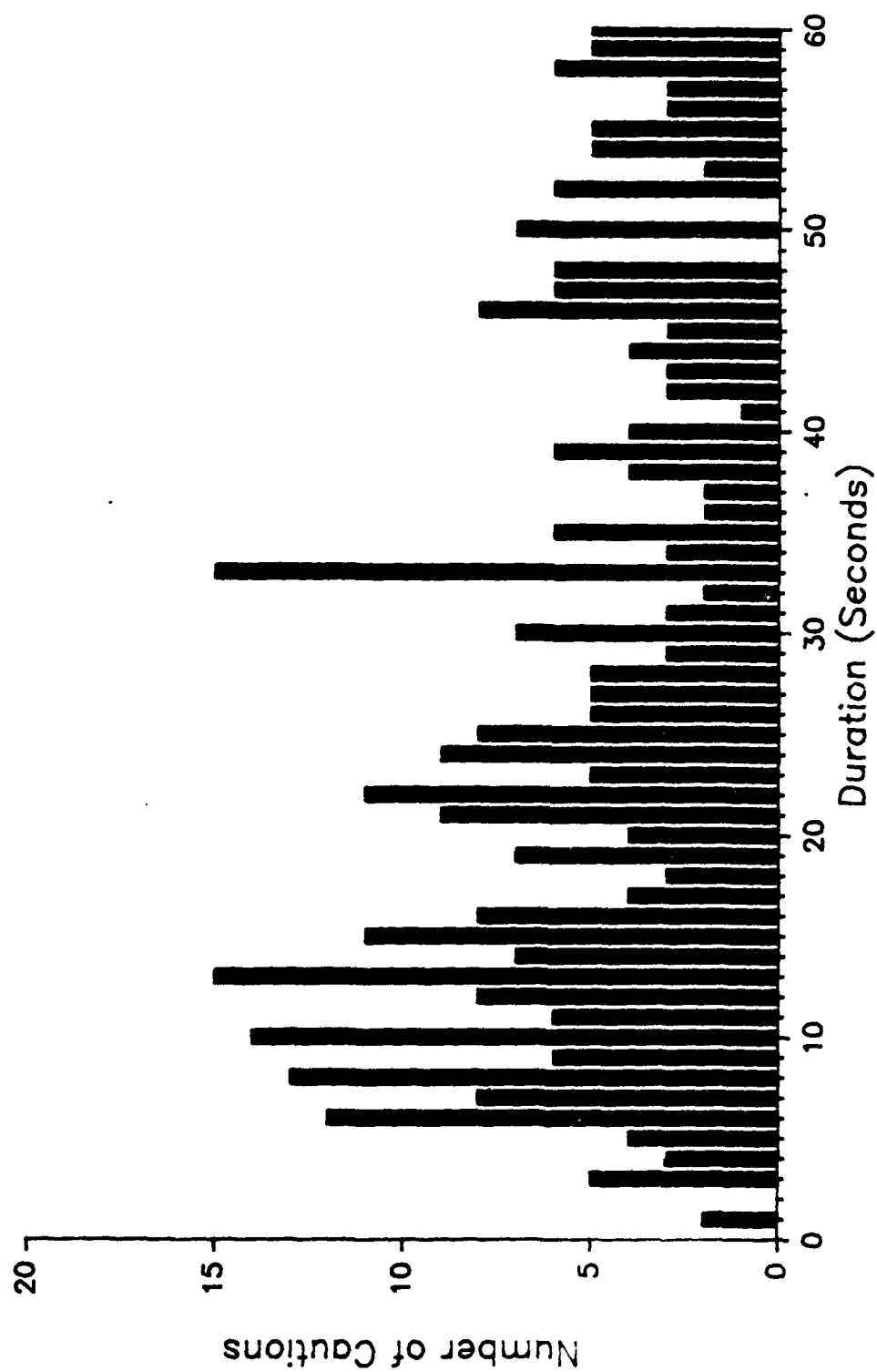


FIGURE 4-14  
DISTRIBUTION OF TCAS CAUTION DURATION (MODE C INTRUDERS)

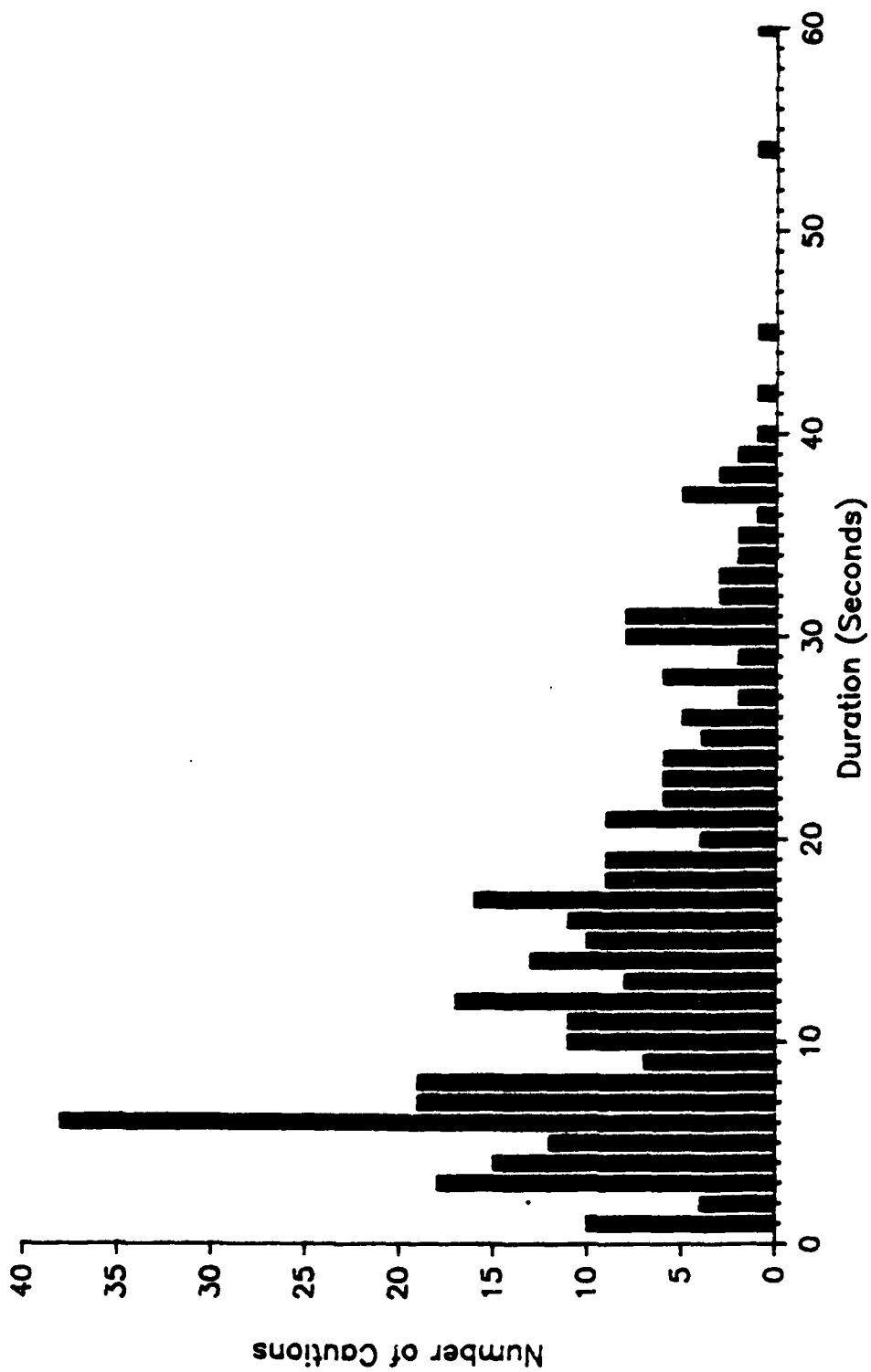


FIGURE 4-15  
DISTRIBUTION OF NON-MODE C CAUTION DURATION

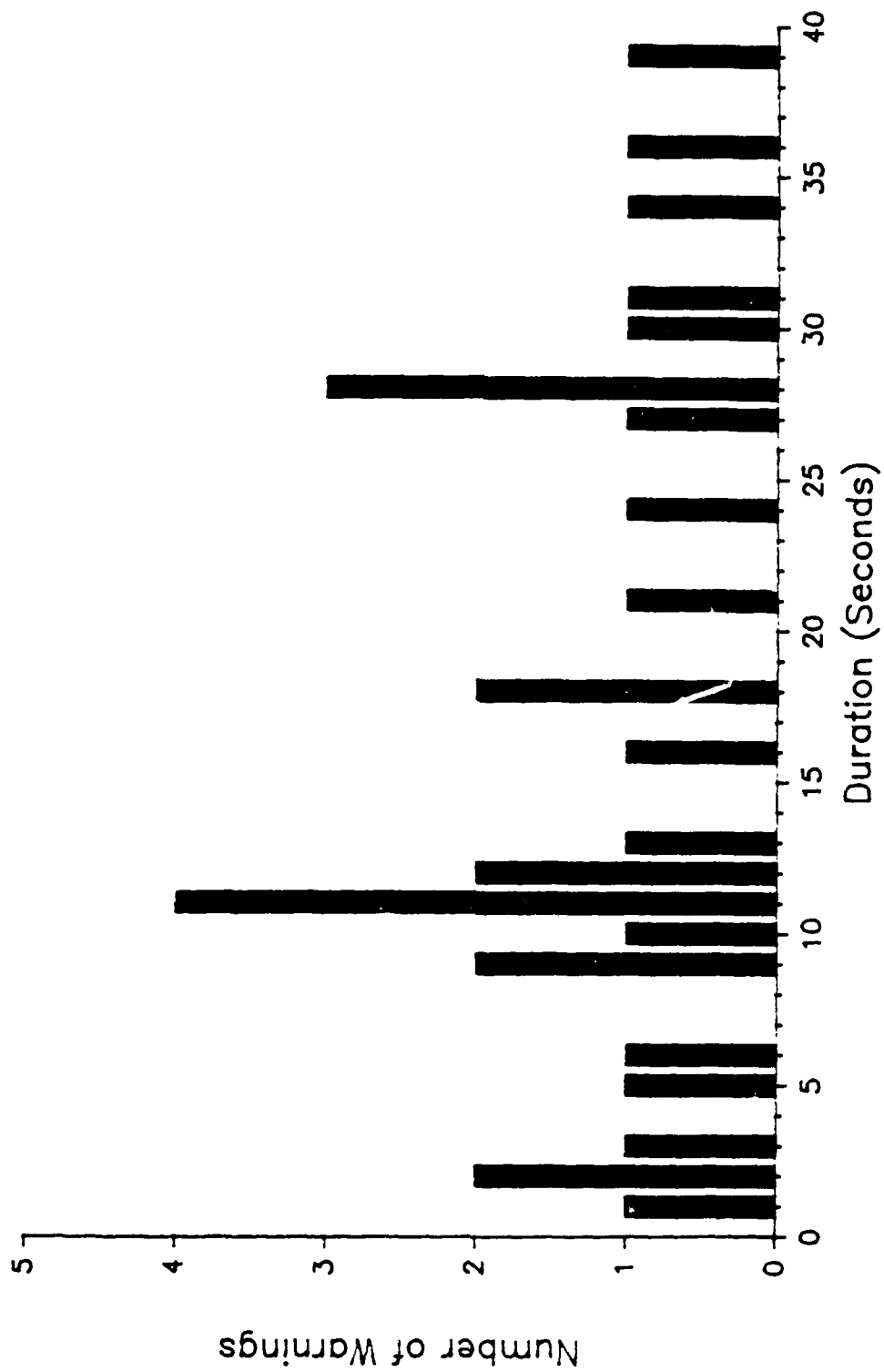


FIGURE 4-16  
DISTRIBUTION OF WARNING DURATION



advisories in which the crew did not respond to an advisory or more than one advisory was displayed during the encounter.

Three of 48 TCAS Warnings were issued without a precursor Caution. MITRE is investigating these three encounters to determine the cause of these "pop-up" Warnings.

#### 4.4.12 Geographic Distribution of Advisories

As shown in Section 4.4.3, approximately 80 percent of the observed advisories occurred at low altitude and within 50 nm of the flight's departure or arrival airport. These observed advisories were further analyzed to determine if a majority of the advisories were occurring in a small number of terminal areas. The analysis indicated that 72 percent of the TCAS Cautions and 84 percent of the TCAS Warnings occurred in the 12 terminal areas where the aircraft operated most frequently.

Figure 4-17 presents the overall percentages of TCAS Cautions, TCAS Warnings, and TCAS Operations at the 12 airports. The figure shows that when the TCAS aircraft operated frequently from an airport, it received more advisories. However, the data in Figure 4-17 are inconclusive for developing an understanding of where TCAS advisories are likely to occur. Each airport has unique characteristics, such as departure and arrival routes, traffic density, and mix of aircraft types. In addition, the routes flown by the TCAS aircraft resulted in its operating at some airports during peak traffic times and at other airports during off-peak times. The data are also based on a small number of Warnings and a relatively small number of operations at some airports (DFW, LGA, MIA, RIC).

In the data set, six of the airports (BWI, DFW, EWR, LGA, RIC, and TPA) have a higher frequency of TCAS Warnings, relative to the number of operations by the TCAS aircraft, than other airports. The only apparent reasons for this occurrence are either the large number of operations handled by these airports, the use of parallel approaches at DFW and EWR, the mix of traffic at RIC and TPA, or the existence of a Piedmont hub at BWI. Neither the observers nor the flight crews reported any unusual operations or ATC handling at these airports during the evaluation.

#### 4.4.13 Time-of-Day Analysis

The observers provided data on the time-of-day at which an advisory occurred. Piedmont's route structure is arranged so that there are no scheduled operations after 0400Z and before 1000Z. The data showed that the occurrence of TCAS advisories was fairly uniform between 1400Z and 2400Z. During most of the evaluation, this corresponds to the period between 1000 and 2000 Eastern Daylight Time. The largest concentration of advisories occurred between 1800Z and 1900Z (1400-1500 EDT) and between 2200Z and 2300Z (1800-1900 EDT). The distribution of the time of advisories is shown in Table 4-4.

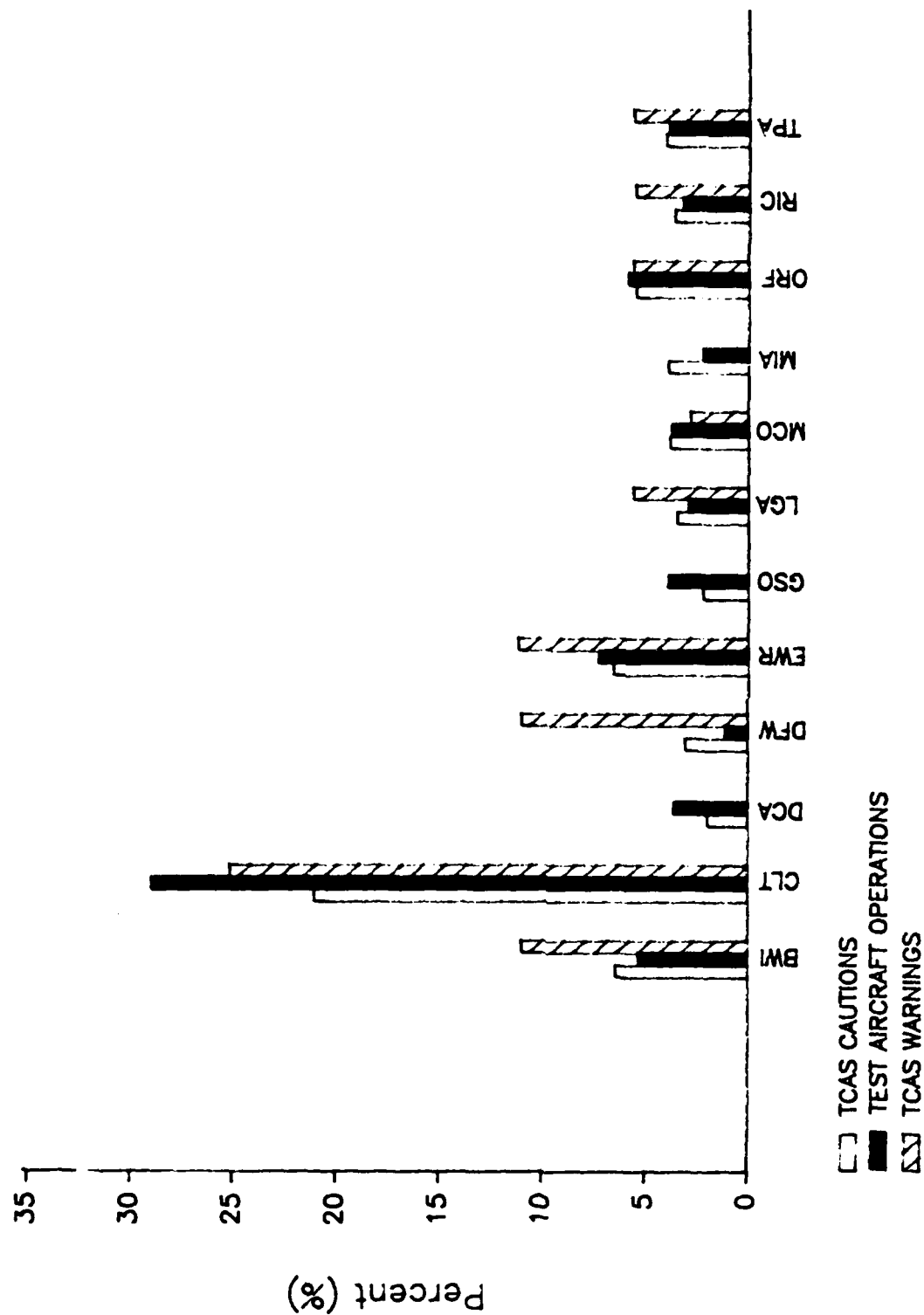


FIGURE 4-17

TCAS ADVISORIES VERSUS OPERATIONS FOR SELECTED DESTINATIONS

Table 4-4. Time-of-Day When Advisory Is Issued

Time-of-Day (Zulu)	Number of Advisories
1000-1100	1
1101-1200	8
1201-1300	19
1301-1400	29
1401-1500	33
1501-1600	33
1601-1700	29
1701-1800	42
1801-1900	56
1901-2000	27
2001-2100	41
2101-2200	34
2201-2300	43
2301-2400	34
0001-0100	19
0101-0200	11
0201-0300	7
0301-0400	1

#### 4.5 QUALITATIVE RESULTS

The quantitative results discussed in Section 4.4 are important for characterizing the nature of TCAS Cautions and Warnings and assessing the performance of the TCAS avionics. The qualitative data provided by the observers and flight crews, however, were the critical data collected during this evaluation. These qualitative data provide information on the crews' understanding of the displays, their use of the system, the impacts of TCAS on crew workload, the utility of TCAS, and human factors/system design information that is not available from the recorded data.

The quantity and level of detail of the data provided on the observer forms varied from observer to observer. Some observers provided extensive details on each Caution and Warning, while others provided only minimal details unless the encounter produced unusual crew responses or display indications. All comments received from the observers and flight crews were routinely reviewed throughout the evaluation to determine if any trends that required correction were developing.

The quality of information provided by the observers and flight crews was excellent and provided key insights into the crews' use of the system. The following sections describe the key observations obtained during the evaluation.

#### 4.5.1 General Assessment

There was unanimous agreement among the flight crews that the information provided by TCAS was useful, timely, and valuable as a backup to the see-and-avoid concept of collision avoidance. The crews further agreed that TCAS was an excellent complement to the separation services provided by ATC.

The observers generally agreed with the crews, but several observers believed that some advisories were unnecessary and may have been a nuisance to the crews. The advisories generally occurred when the TCAS aircraft was operating in the terminal area or when the intruder and the TCAS aircraft began to diverge. In some cases, the observers discussed their views with the crews after landing and noted that the crews did not consider these advisories a nuisance. The crews did feel, however, that the aural portion of the system was sometimes distracting during a high workload environment, such as that prevailing during an approach. The crews were generally of the opinion that it was better to display too much traffic than too little.

#### 4.5.2 Installation-Specific Comments

The cockpit installation of the TCAS equipment for the Phase II evaluation, shown in Figure 4-18, consisted of two glareshield-mounted Caution/Warning lights, two modified IVSIs, a modified weather radar CRT, a TCAS control panel, and a dedicated speaker. The location of each component was dictated by existing instrument location (IVSI, CRT), availability of cockpit mounting provisions and space (speaker, control panel, and Caution/Warning lights), or human factors considerations (Caution/Warning lights). While the cockpit layout of the TCAS components was generally acceptable and did not cause any major problems, the crews and observers noted several areas that should be improved on subsequent installations.

As shown in Figure 4-18, the two glareshield lights were suspended below the glareshield, approximately in line with the edges of the center control stand. In this location the lights blocked the captain's normal view of the number 1 engine EPR and NI indicators and the first officer's view of the number 3 engine EPR and NI indicators. The crews noted that it was especially important to be able to see these indicators during the take-off roll and initial climb. This problem can be resolved by mounting the lights in the glareshield or on the instrument panel. If the lights are mounted on the instrument panel, care should be exercised to ensure that the pilot can still see them with peripheral vision while looking outside for traffic. (This is especially important if an aural alarm is not provided when an advisory is removed or a Warning is downgraded.)

The crews and observers were also critical of the inability to control the brightness of the Caution/Warning lights. The lighting intensity was observed to be satisfactory for all daytime operations, including direct sunlight. However, at night the lights were much too bright, and the crews felt "blinded" by their intensity. This problem can be resolved by wiring the Caution/Warning lights into the aircraft's Master Warning Test and Dim switch. This is preferable to having a

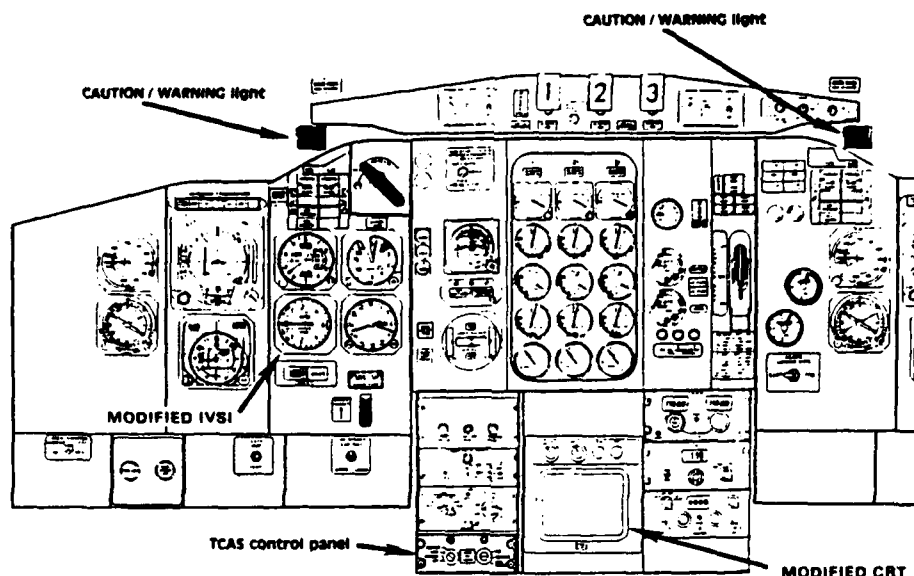


FIGURE 4-18

#### LOCATION OF TCAS COCKPIT EQUIPMENT

separate control for the TCAS lights' intensity, since no new crew actions will be required to dim the lights for night operations. The intensity of the other lights on TCAS displays was acceptable for both day and night operations, although the green climb and descend arrows on the IVSIs were sometimes washed out in direct sunlight conditions.

Several first officers complained about the inaccessibility of the TCAS Control Panel. As shown in Figure 4-18, the TCAS Control Panel is mounted on the lower left side of the forward electronic control panel. The First Officer must lean forward and to the left to reach the two switches on the Control Panel. This is an awkward maneuver, especially when the throttles are set to climb or cruise power. The first officers are generally reaching to select the TCAS/TRACKS mode, which is controlled by the right switch on the panel. (The captain nearly always controlled the selection of STANDBY or ON and the TCAS/WX or WX modes). The awkwardness was compounded by the short duration display (15 seconds) provided by the TCAS/Tracks mode and the requirement to rotate the switch momentarily downward to activate the display. Piedmont's cockpit layout dictated the location of the control panel, and there is probably no other available location that would alleviate this problem.

Since accessibility will probably be a problem in other aircraft types and cockpit layouts, two potential solutions are recommended. Both solutions are applicable to systems with a momentary implementation of the TCAS/TRACKS function. First, a push button could be used instead of a rotary switch on the TCAS Control Panel for selecting the TCAS/TRACKS mode. Such a switch is already used as the IDENT button on some transponder control heads. While this substitution would not eliminate the awkward reach, it would eliminate the difficulty of rotating the switch. The second possible solution is to use a push button mounted on each control yoke, completely eliminating the reach problem and allowing

the two pilots the same ease of access. If this implementation were used, the control panel could be located in less accessible locations, since the other switches are used infrequently. The awkward reach for the TCAS/TRACKS mode could also be eliminated by displaying the TCAS/TRACKS information on a full-time basis.

The problem that caused the greatest confusion during the evaluation was the interface between TCAS, the weather radar control panel, and the weather radar CRT. The modified weather radar CRT has three modes: HOLD, SCAN, and LIST. The HOLD and SCAN modes are used with the weather radar, and LIST is used only for TCAS. The operation of the weather radar's receiver/transmitter is controlled from a control panel mounted just above the TCAS Control Panel (see Figure 4-18). The radar has several modes, including Standby, Normal, Contour, and Map. The normal operating configuration of the radars in Piedmont aircraft has the radar in Standby and the CRT in SCAN during operations in clear weather. When rain or thunderstorms are being avoided, the radar operating configuration is changed to Normal and SCAN, which requires changing only one switch on the Radar Control Panel. However, the TCAS modification to the CRT requires that the CRT be placed in the LIST mode while the radar is in Standby. This design was selected because power is not supplied to the indicator while the radar is in Standby. Thus the normal operating configuration of the CRT had to be changed. If the CRT could display weather information while in the LIST mode, this problem might not have been observed. However, when the radar is in the Normal, Contour, or Map mode, the CRT must still be in the SCAN mode to display the weather data. TCAS information will also be displayed in this configuration. There were a number of encounters during Phase II in which the radar was in Standby, the CRT in SCAN, and TCAS ON. This resulted in an aural tone followed by the spoken word TRAFFIC, but with no display on the CRT.

While the interface problem may not exist in precisely the same way in other installations, its existence does underscore the need to exercise caution when the operation of TCAS alters a long-standing operation of existing on-board systems. Experience in operating TCAS will eventually eliminate any confusion, and the new operating procedures will become routine; but the first few months of operation may be hampered by this type of problem. The interface between the radar and TCAS was addressed in the training video (see Section 2.8) and in the Operations Manual Supplement (see Appendix A). After this problem was discovered in the first week of the evaluation, the TCAS instructors began emphasizing the need to place the CRT in the LIST mode when the radar was in Standby to obtain the TCAS display. Although this increased emphasis reduced the number of encounters that were aurally annunciated but not displayed, the problem continued to occur periodically during the evaluation. The problem never resulted in a compromise of safety, but it did create confusion.

#### 4.5.3 Visual Acquisition

One of the major benefits of TCAS demonstrated during the Phase II evaluation was assisting the flight crews in visually acquiring nearby and threat aircraft. This benefit was especially apparent when the threat aircraft was equipped with an altitude reporting transponder.

Figure 4-19 presents the percentage of intruder aircraft that were visually acquired during an encounter that caused a TCAS Caution to be issued. As shown in this figure, the presence of an encoding altimeter on board an intruder greatly enhances the probability that a crew will visually acquire the intruder. Although only 20 percent of the non-altitude reporting intruders were visually acquired, the Caution was still considered useful information, since ATC advisories were issued against 37 percent of the intruders causing a Caution.

There are two primary reasons for the higher probability of visually acquiring intruders equipped with altitude reporting transponders. First, TCAS is unable to determine an intruder's altitude, and Cautions are thus based only on its range from and rate of closure with the TCAS aircraft. Since non-Mode C Cautions are issued whenever the TCAS aircraft is below 15,500 feet MSL, the protection provided by TCAS is greatly expanded in the vertical plane. Therefore, a crew must scan a large volume of airspace (ground to 15,500 feet) while looking for the intruder. The lack of altitude information from the intruder also precludes a CRT altitude display and thus limits the utility of the CRT display in focusing the visual scan of the crew.

As a further measure of the utility of TCAS in aiding visual acquisition, the observers provided data on the sequence of four events that occurred during each encounter: ATC advisory, TCAS Caution, TCAS Warning, and visual acquisition. These data indicate that 78 percent of the intruders visually acquired during an encounter were acquired after a Caution was issued. In 108 encounters, an ATC traffic advisory was issued prior to the Caution but visual acquisition was not obtained in 64 of these encounters until after a TCAS Caution was issued.

#### 4.5.4 TCAS/TRACKS Mode Usage

The TCAS/TRACKS mode provided a crew with a 15-second display of all transponder equipped traffic within  $\pm 1,200$  feet and 4 nm of the TCAS aircraft. Non-altitude reporting aircraft within 4 nm were displayed when the TCAS aircraft was below 15,500 feet MSL. This operating mode could be selected by a crew during any phase of flight.

The training program and operations manual informed the crew of the availability of this feature, but no specific procedures were defined for using it. Instead, the crews were told that the feature was available for use any time during a flight to show nearby aircraft that were not causing a TCAS Caution or Warning to be displayed. As a result, the use of the TCAS/TRACKS, or TRACKS, mode varied from crew to crew. Some crews never used this feature, while others used it extensively in the terminal areas and while operating below 10,000 feet MSL. It was also observed frequently that this display mode was selected immediately after an ATC advisory was issued, after a Caution or Warning was discontinued, and during maneuvering in the terminal area.

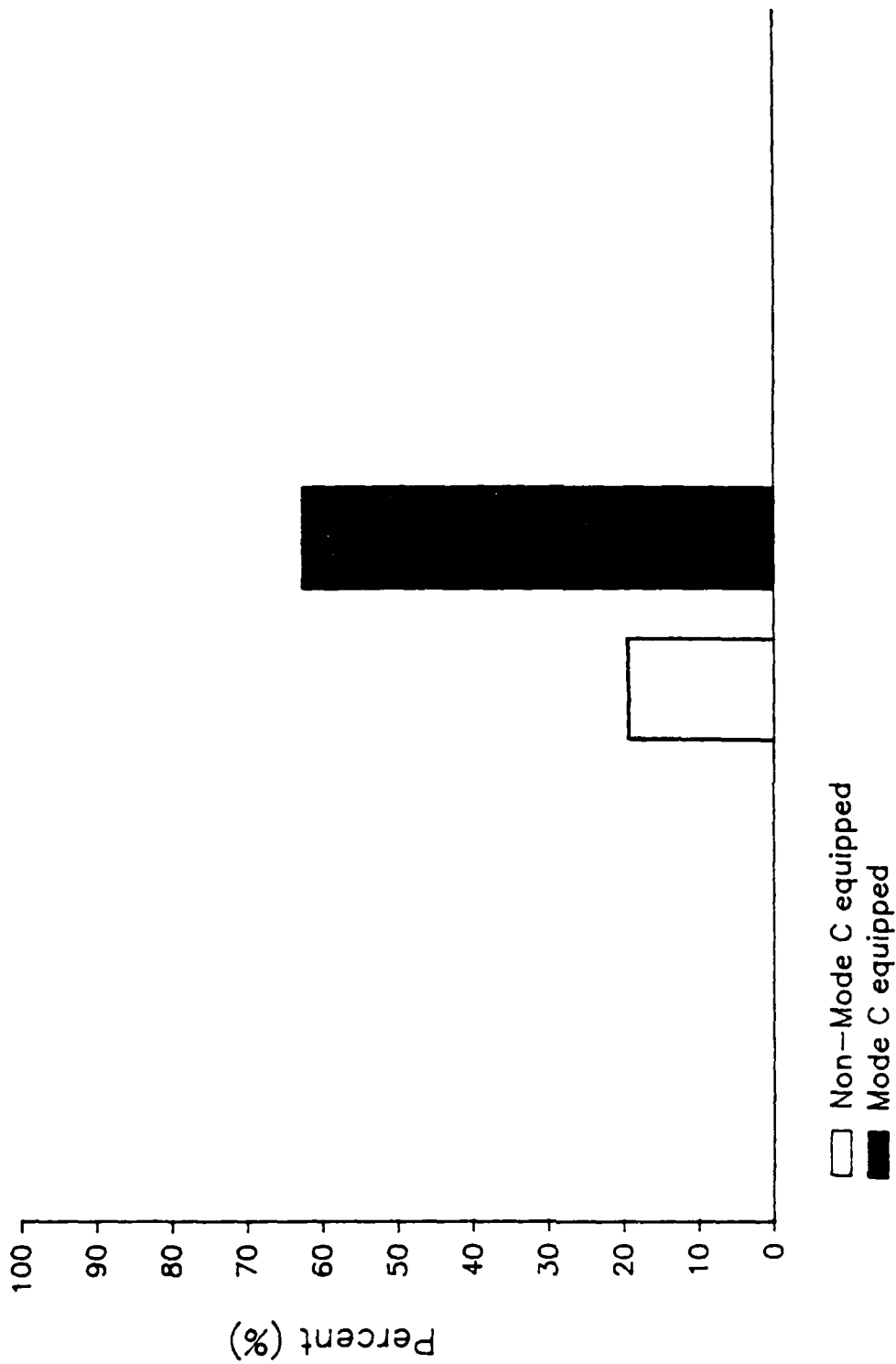


FIGURE 4-19  
VISUALLY ACQUIRED TRAFFIC



While there was no demonstrated consensus regarding the use of this mode, the comments received from the crews indicated that the feature was useful in supplementing both ATC traffic advisories and the see-and-avoid concept. The comments also indicated a difference of opinion regarding the implementation of this mode. There are proponents of having this mode displayed continuously as well as proponents of keeping it as a momentary display. The advocates of the momentary display believe that a full-time display of traffic would become a distraction. The advocates of a full-time display believe that too much time was spent selecting the TRACKS mode when the information was desired. On the basis of these opinions, the best implementation appears to be one that permits a crew to select whether the TRACKS mode data are displayed continuously or momentarily.

There was unanimous agreement among the crews using the TRACKS mode that the display parameters of 4 nm and  $\pm 1,200$  feet were too restrictive, especially in the en route environment. At higher altitudes, ATC will often issue traffic advisories against aircraft more than 10 miles away. After these advisories were issued, the crews often selected the TRACKS mode to obtain additional information on the intruder. Because of the 4 nm range limitation, the CRT display was blank. When the TCAS aircraft is operating above FL 290, the present implementation of this feature is useless, since traffic is separated by 2,000 feet. The solution is to either expand the display parameters automatically as the TCAS sensitivity level is changed or to allow the pilot to select the altitude and range to be displayed.

Use of the TRACKS mode during the Phase II evaluation was beneficial to the crews and did not exceed the mode's intended function. There were no reported instances in which the TCAS/TRACKS data were used to perform either a horizontal maneuver or a vertical maneuver to increase separation from an intruder. The TCAS/TRACKS mode was often used to monitor the relative position of other aircraft, especially the aircraft being followed, during visual approaches. There were no observed instances in which the displayed data were used to adjust speed or spacing during a visual approach.

#### 4.5.5 Pop-Up Warnings

Three of the 48 Warnings were classified as pop-ups -- i.e., the Warning was issued without a Caution being issued. The reason for these pop-up encounters is under investigation by MITRE. Two of the three pop-up warnings were corrective and required the crew to change their descent rate. The third pop-up warning was preventive and did not require a change in the existing vertical profile.

In the two corrective pop-up encounters, the lack of a precursor Caution did not adversely affect the crews response to the Warning. In both cases, the TCAS aircraft was descending and the advisory required a reduction in the descent rate. Each crew smoothly and quickly reduced its descent rate such that the vertical speed indicator was not within the IVSI's lighted segment lights. The crews later questioned why a

Caution was not issued, but the important observation was that their responses to these advisories were not markedly different from their responses to Warnings preceded by a Caution.

#### 4.5.6 TCAS Impacts on ATC

The operation of TCAS on one aircraft had little or no impact on the ATC system. Only two encounters resulted in a deviation from an ATC-assigned altitude. In both cases, the deviation was relatively small -- approximately 200 feet in one case and approximately 300 feet in the other. The deviation in one encounter (see Appendix D, Warning 37) was caused by the crew's failure to follow the first Warning to LIMIT VERTICAL RATE - DO NOT CLIMB while climbing to an assigned altitude.

Only two comments were received about the impacts of TCAS on ATC during the Phase II evaluation. In the first week of the evaluation, some concern was expressed that the use of TCAS was causing extraneous communications between the TCAS aircraft and ATC. These communications were related to traffic displayed to the crew on the weather radar CRT. A note was placed on the flight release for the TCAS aircraft asking the crews not to make unnecessary radio calls to ATC to verify TCAS-displayed data. This note, together with the crews' increasing familiarity with TCAS, eliminated the problem. After the first two weeks of the evaluation, there were no reports of unusual or unnecessary communications with ATC.

The other comment was provided by a controller from the Chicago Air Route Traffic Control Center who was working the TCAS aircraft when the aircraft received a TCAS Warning. (This Warning is described in detail in Section 5.4.) The request made by the crew during this encounter resulted in the controller issuing a revised clearance to the flight. The controller stated that he was able to provide an amended clearance on that day (a Saturday afternoon) but might have been unable to provide the amended clearance on a weekday afternoon.

The Phase II evaluation provided a limited quantity of data on the impacts of TCAS on ATC. These preliminary data indicate that the presence of TCAS on one aircraft does not affect ATC operations. Additional data, with more than one TCAS-equipped aircraft operating in the NAS, are necessary for a precise assessment of how TCAS affects ATC.

#### 4.5.7 Use of TCAS Caution Information

Two simulator studies conducted after the Phase I evaluation showed a high incidence of pilots using the displayed TCAS Caution data to execute maneuvers to increase separation from an intruder. The training program used during the Phase II evaluation and the Operations Manual Supplement emphasized that the displayed TCAS Caution data were for information only and that maneuvers were not to be made solely on the basis of TCAS Caution data. The training program validation (see Section 2.8.2) demonstrated that the Caution information was being used correctly by the Piedmont crews. The Phase II evaluation further demonstrated the proper use of these data, since there were no observed instances of a crew's performing a vertical or horizontal maneuver solely on the basis of the TCAS Caution display.

#### 4.5.8 Human Factors Issues

Before the Phase II evaluation was initiated, the ACO's flight test pilots and various industry organizations expressed numerous concerns regarding the displays and procedures to be used during the evaluation. Some of these concerns resulted in changes to the aural annunciations and colors of the displays following an evaluation at the FAA Technical Center late in 1983. Additional work on TCAS human factors issues is continuing to enhance or refine the displays for TCAS II and to define the displays for TCAS III. Nevertheless, the displays used in the Phase II evaluation were simple, effective, and easy to interpret. The following paragraphs describe specific human factors issues addressed by the Phase II evaluation.

##### 4.5.8.1 IVSI Interpretation

The modified IVSIs were used to indicate the recommended vertical escape maneuvers to the crews. The climb and descend arrows were used to indicate the need to establish a vertical rate of 1,500 fpm or maintain the existing rate if that rate was greater than 1,500 fpm. The crews responded properly to all CLIMB and DESCEND advisories. The IVSIs also used a series of segment lights to indicate the need to limit the climb or descent rate to 0, 500, 1,000, or 2,000 fpm. Thirty-one advisories issued during the evaluation used the segment lights. There were no observed misinterpretation of the segment lights during the evaluation. (There was a display interpretation problem in the second training program evaluation, as discussed in Section 2.8.2.) A survey of the pilots who used the system and received a TCAS Warning indicated that the IVSI display was effective and easy to use. The pilots did not recommend any changes to the display. Similarly, the observers did not recommend any changes to the IVSI.

##### 4.5.8.2 CRT Display

With one exception, there were no reported or observed problems in interpreting the information displayed on the modified weather radar CRT. The colors and symbology were acceptable to the crews, and no changes were recommended by either the pilots or the observers.

There was a problem with the interpretation of a "No Bearing" TCAS Caution, especially when Proximate traffic was displayed with bearing information at the same time. On a small number of encounters, the crew initially looked for the Proximate traffic before looking for the Caution traffic. There was also confusion about the exact meaning of the "No Bearing" display, the meaning of the information contained in the "No Bearing" display, and the reason for displaying traffic in tabular form and not as a triangle at the proper location (bearing) on the CRT. This appears to be a training issue; additional emphasis should be placed on the meaning of this display in future training programs. No Warnings were issued against intruders with no bearing information available.

#### 4.5.8.3 Quality of Displayed Data

No comments were received regarding the sharpness, brightness, and readability of either the IVSI or CRT displays. It was observed that the blue displays on the CRT can be washed out by direct sunlight.

When the weather radar is used in the Map mode during night operations, the brightness must be turned down to prevent "blinding" the crew. The brightness is a result of the density of the radar returns shown on the CRT in this mode. When a TCAS advisory is issued or the TRACKS mode is selected while the radar is in the Map mode, the TCAS display does not have sufficient brightness to be visible. As the Map mode was observed to be used very rarely in flight, this display problem should have minimal impact on the crews. This problem did not occur when the radar was used in the Normal or Contour modes.

#### 4.5.8.4 Amount of Displayed Information

The pilot survey and observer comments indicate that the amount of information displayed on the CRT is satisfactory. There have been no comments regarding the need for additional data on the intruder aircraft.

The observers and crews have commented that the display of a No Bearing, non-altitude reporting intruder is virtually useless. The only information shown to the crew in this situation is the intruder's range. There were no reported cases of this display's leading to visual acquisition of the intruder aircraft. MITRE has proposed a modification of the TCAS logic to inhibit the display of non-altitude reporting intruders when no bearing data are available. This should not adversely affect the utility of TCAS and will enhance pilot acceptance of the system.

#### 4.5.8.5 Aural Annunciations

No misunderstanding of the aural tones or spoken words was observed during the Phase II evaluation. Some pilots did report having trouble understanding the word "Limit" in the term "Limit Vertical Rate." These remarks were made following a self-test and not during an actual encounter.

The pilots responding to a written survey were generally of the opinion that the aural annunciation was necessary to indicate a TCAS advisory. There were comments, however, that showed a desire to modify the aural annunciations during operations near an airport. Some crews thought that they received too many aural annunciations when a Warning was issued while they were on approach. Each Warning includes a European siren followed by a spoken word or phrase. The word or phrase continues until the crew silences it. When the Warning is downgraded, e.g., changed from CLIMB to DO NOT DESCEND, another phrase is spoken. When the cockpit workload is high, these aural annunciations can be distracting. In such encounters, it may be desirable to eliminate either the European siren or the words to reduce the noise in the cockpit. Simulation studies to assess a crew's response to different aural annunciations are necessary before a final recommendation on this issue can be developed.

Many pilots and observers commented on the need for an additional aural annunciation to indicate that a TCAS Warning has been removed and the advisory discontinued. If a pilot silences the aural alarm after recognizing that a Warning has been issued, the only indications that the encounter has ended are the clearing of the IVSI display and the extinguishing of the Caution/Warning light. These indications can be missed if the crew is looking outside for the intruder. The addition of an aural annunciation to signal that the encounter has ended and the Warning has been removed should assist in minimizing deviations from the aircraft's original clearance. During the Phase II evaluation, the aural annunciation was silenced by the crew in 25 percent of the Warnings.

The volume and clarity of the aural annunciations was satisfactory under most operating conditions. When the aircraft is operating at low speeds (less than 250 knots) with low power settings, the ambient cockpit noise is very low and the volume of the TCAS aural annunciations is too high. Thus the aural annunciations often startle the crew and can make it difficult to hear other crew members or ATC communications. An ambient-noise monitor in the cockpit could be used to control the volume of the annunciations. If a single volume is used, it must be loud enough to be heard when the volume of the ambient cockpit noise is high.

#### 4.5.8.6 Caution/Warning Lights

The pilots and observers considered the Caution/Warning lights a useful and necessary part of the system. Comments about the lights' location and brightness are discussed in Section 4.5.2.

#### 4.5.9 Understanding of TCAS Operation

Because a large number of crews participated in the Phase II evaluation and the TCAS was installed on only one aircraft, the crews did not have sufficient exposure to TCAS to become completely familiar with it. One concept that caused confusion throughout the evaluation was that TCAS is a time-based system and advisories are not issued solely on the basis of distance. The confusion was sometimes compounded by the TRACKS mode use of distance and by the presence of the two-mile range ring on the CRT. Not all crews fully understood (initially) that the two-mile range ring was not used to determine when a Caution should become a Warning. This issue should resolve itself as pilots obtain more experience with TCAS.

To assist crews in acquiring a more detailed understanding of the TCAS design, the technical details of the TCAS design and installation should be made available to the crews. This information should not be included in the training program, since it is not required for safe operation of the system.

#### 4.5.10 Impacts of TCAS on Pilot Workload

Since the Phase II evaluation represents the first time crews have been permitted to use the information displayed by TCAS, it was important to assess the effects of TCAS on the crew's workload. No quantitative

measures of workload were taken during the evaluation, so the observer and pilot comments were used in developing this assessment.

Overall, the crews demonstrated that the use of TCAS could be integrated with the existing cockpit tasks. The integration occurred with no apparent problems for the crews in recognizing a TCAS advisory and determining if immediate action was required or if other higher priority tasks could be accomplished first. In taking action in response to an advisory, the crews readily used the displayed information to either visually acquire the intruder or to maneuver to increase separation from an intruder. In no case was TCAS found to be a distraction to the crews nor did it interfere with other cockpit tasks.

This integration of TCAS can be demonstrated by examining a crew's response to several TCAS advisories. On the first day of TCAS operation, a Caution was issued as the TCAS aircraft was initiating a turn from the base leg onto final and descending at a moderate rate. The first officer continued the turn to final while the captain visually acquired the traffic. There were no noticeable deviations from the original flight profile. A second Caution was displayed on final approach just before the landing gear was extended as the aircraft passed the outer marker. The first officer called for gear down just after the Caution, continued to fly the approach, and periodically looked for the traffic. The captain extended the gear while looking for the traffic and pointed out the traffic to the first officer after visual acquisition. The important observation from these two encounters is that the crew continued flying the original profile while searching for the intruder.

The first TCAS Warning occurred during a descent into the Newark, New Jersey, terminal area (see Warning Number 1 in Appendix D). The Warning was issued just before the TCAS aircraft crossed a VOR at which a course change would be made. The Warning was DO NOT DESCEND, requiring the TCAS aircraft's descent to be momentarily halted. The aircraft was leveled in a smooth, controlled manner while it was in the turn to intercept the new course. The turn and descent were accomplished smoothly and in a coordinated, timely manner, such that there was no overshoot of the new course. After the intruder passed and the Warning was removed, the original descent rate was reestablished. Again, the important observation is that the recommended vertical maneuver was accomplished without compromising the requirement to intercept the new course.

A third example of the use of TCAS is provided by Warning Number 10 (see Appendix D). In this case, the TCAS-displayed information was used to visually acquire the intruder aircraft, but the crew chose not to follow the Warning, because of their location and the geometry of the encounter. The Warning occurred when the TCAS aircraft flew through the final approach course while the intruder was established on final for the parallel runway. The crew recognized that following the advisory would result in a missed approach, and they resolved the encounter by initiating a turn to final. The observation of interest during this encounter is that the crew used the information presented by TCAS but did not blindly follow the advisory. Instead, they disregarded TCAS and used other available information to resolve the encounter.

Including TCAS in the cockpit requires a crew to operate a new system and cope with its associated displays and annunciations, imposing new tasks on a busy crew. The Phase II evaluation has shown, however, that crews can interpret the TCAS displays and integrate the use of TCAS with their existing tasks without detracting from the other tasks and compromising the safety of the aircraft. The crews have also demonstrated the ability to assign the proper priorities to using TCAS while performing their other tasks.

#### 4.5.11 TCAS Design Parameters

The crews and observers made only a few comments about the parameters used in deciding if an advisory should be issued. They believed that the tau values used in the Resolution Advisory logic provided ample time to recognize the displayed advisory, decide on a course of action, and respond to the advisory when necessary. The crews were also satisfied with the tau values used to display Cautions against altitude reporting intruders.

Several comments indicated the tau values used for displaying non-Mode C intruders were too small. To prevent the display of nuisance advisories against non-Mode C intruders, Cautions are not issued until the TCAS Warning range tau criterion is satisfied. In most cases, this tau value is 25 or 30 seconds. The crews commenting on this design feature thought that insufficient time was provided to recognize the advisory, visually search for the traffic, and coordinate a maneuver with ATC if the traffic was not visually acquired. While the crews are instructed not to maneuver using displayed Caution information, they came to trust the system to such an extent that they felt uncomfortable when a non-Mode C intruder was converging with the TCAS aircraft but was not in sight. If a higher tau value is used for non-Mode C intruders, more intruders will be displayed to the crew, which may become a nuisance. Insufficient data were provided to permit a recommendation regarding tau values. Until further data are collected, the tau values should remain unchanged.

#### 4.5.12 Nuisance Advisories

During the Phase II evaluation, concern was expressed by some organizations that the TCAS advisory rate (see Section 4.4.1) was too high and that TCAS was issuing unnecessary advisories that could be considered nuisances. Since there is no agreed-to definition of a nuisance or unnecessary advisory, it is difficult to access how often such an advisory occurred. The observer data indicates that the observers generally felt that unnecessary Warnings occurred when a mile or more of horizontal separation existed between the intruder and TCAS aircraft; when the Warning occurred during simultaneous, parallel approaches in VMC; and when the Warning was issued as the intruder was passing through the TCAS aircraft's 3 o'clock or 9 o'clock position.

Although some observer's felt that these types of advisories were unnecessary, the pilots operating the system felt that the only unnecessary Warnings occurred when the intruder was already passing the

3 o'clock or 9 o'clock position. There were three such advisories during the evaluation. MITRE has developed a technique for eliminating these advisories which is described in Section 6.4. None of the other Warnings were considered unnecessary or a nuisance by the crews.

There were two types of Cautions that the crews considered nuisances. Numerous Cautions against non-Mode C intruders were displayed for less than five seconds (see Section 4.4.11). When the TCAS information is displayed for such a short period of time, insufficient time is provided for the crew to recognize a Caution is being issued, look at the display, and interpret the displayed data. In several cases, by the time the crew looked at the display, it was blank. These advisories were of no use to the crew and were thus considered a nuisance. The short duration displays also made some crews wonder if the system was performing properly and thus, decreased their level of confidence in the system.

There were also many comments on the display of Cautions against intruder aircraft with 1,000 feet of vertical separation from the TCAS aircraft while both aircraft were level. Since 1,000 feet is the legal separation for aircraft operating IFR below FL290, a number of the crews viewed these advisories as a nuisance. Consideration should be given to not displaying Cautions against aircraft with 1,000 feet of separation when both the intruder aircraft and TCAS-equipped aircraft are in level flight.



## CHAPTER FIVE

### CONFLICT CASES OF PARTICULAR INTEREST

During the Phase II evaluation, periodic reviews were held with personnel from Piedmont, the FAA, and interested industry organizations. These reviews presented data from the observers, statistics on the recorded data, and the details of each TCAS Warning. In the review of encounters causing a TCAS Warning, several were identified by ARINC Research, MITRE, and the FAA as Warnings that warranted more detailed analysis. They represent suspected atypical operation of the avionics or encounters that caused some operational concern to be expressed by the crew, ATC, or the observer. None of the encounters described in the following sections placed the TCAS aircraft in a hazardous situation.

Four of the 48 TCAS Warnings resulted in further analysis by MITRE, FAA, and ARINC Research. These are described in the following sections, with accompanying plots of the encounter obtained from the observer notes, recorded TCAS data, ATC data tapes, or a combination of these sources. The observer plots show the TCAS information displayed on the CRT and a line drawing of the encounter's vertical geometry.

For the encounters in which TCAS recorded data or ATC data were available, two types of plots were developed by MITRE. The first shows the relative bearing and range of the intruder aircraft throughout the encounter. The data are presented in a plan view; a turn by either aircraft causes a change in the relative bearing of the two aircraft. Each symbol on the chart represents a one-second update of the data.

The second type of plot developed by MITRE is an x-y plot that contains several graphs. On these plots, elapsed time from the start of the encounter is plotted along the x axis. The following types of data are plotted in three graphs whose values are shown on the y axis.

- The top plot shows the current altitude of the TCAS aircraft, ZOWN, and the threat aircraft, ZINT, versus system time. The scale for the altitude plot, in feet, is on the left vertical axis. The range between the two aircraft, R, is also plotted. The scale for R, in nm, is on the right vertical axis.

- The middle plot is a plot of current altitude separation, A, and projected altitude separation, VMD, versus system time. The thresholds for threat detection, ZTHR, and positive/negative advisory selection, ALIM, are both plotted as dashed lines, with their values shown in the legend.
- The bottom plot shows the range tau (TAUR) and vertical tau (TAUV) values plotted as the ordinates. The thresholds associated with TAUR and TAUV, TRTHR, and TVRHR, respectively, are shown as dashed lines, and their values are printed in the legend.

At the top of the plot is a representation of the TCAS Warnings generated during the encounter. An arrow indicates a CLIMB or DESCEND advisory; an arrow with an X on the shaft indicates a DO NOT CLIMB or DO NOT DESCEND advisory; an arrow with bars on the shaft indicates a LIMIT CLIMB or LIMIT DESCENT advisory, with three bars signifying 500 fpm, two bars 1,000 fpm, and one bar 2,000 fpm.

A vertical line is drawn on the plots to indicate when the Warning was issued.

In addition to these four encounters, pop-up Warnings and the Warnings encountered near an airport operating simultaneous approaches to parallel runways are reviewed.

#### 5.1 TCAS WARNING 6

On April 7, 1987, the TCAS aircraft was operating as Piedmont Flight 79 en route from Charlotte, North Carolina, to Dallas-Ft. Worth, Texas. At approximately 1822Z the aircraft was on the DFW 030 degree radial at 11 DME and was level at an assigned altitude of 11,000 feet. The encounter began with a TCAS Caution showing the intruder aircraft at the 12 to 1 o'clock position, 1,200 feet below Flight 79, and out of CRT display range. The crew gained visual contact with the traffic after the Caution was issued. As the range between the two aircraft continued to decrease, a DESCEND Warning was issued. The CRT display showed the intruder aircraft at 1 o'clock, 700 feet below, and level. Since the captain had the intruder in sight, and had determined that Flight 79 would pass above and behind it, he elected to ignore the Warning and remain level. As a result, a TCAS Invalid was issued. The encounter ended with the intruder aircraft at 9 o'clock and 1.5 miles of lateral and 800 feet of vertical separation indicated. Flight conditions were day, VMC, with 15 miles of visibility. No ATC advisories were issued during the encounter.

The observer commented that a LIMIT VERTICAL RATE (DO NOT DESCEND) command, not a DESCEND command, was expected. The DESCEND advisory placed the two aircraft in an altitude crossing situation. A preventive rather than corrective advisory might have been more appropriate, although since Flight 79 had just leveled, the own-aircraft tracker may have still sensed a descent and issued the Warning on that basis.

Because of a data recorder problem, no TCAS data were recorded for this encounter. Concern was expressed about the DESCEND advisory since it would have caused an altitude crossing maneuver, and the crew's decision not to follow the Warning resulted in a TCAS Invalid. In an attempt to recreate the encounter, ATC data tapes were requested from DFW Regional Approach Control and the Ft. Worth Center. Neither facility had recorded data that contained the tracks of Flight 79 and the intruder aircraft.

Once it was determined that no recorded data were available, MITRE began to use the information provided in the observer notes to recreate the encounter so that the performance of TCAS could be validated. Figure 5-1 shows the encounter's geometry as recorded by the observer. With this information, MITRE used its knowledge of the TCAS logic and its Monte Carlo simulation to determine what conditions would cause the issuance of a DESCEND advisory. Figure 5-2 illustrates the only condition found in this analysis that can cause a DESCEND advisory. As shown in the figure, the TCAS Caution was issued with both aircraft in level flight with adequate vertical separation. As the range between the aircraft decreased, adequate separation was maintained and the TCAS projections indicated that a Warning would be unnecessary. However, the intruder's reported altitude changed by 100 feet within one second because of a slight change in the aircraft's actual altitude and the quantization of the reported altitude. TCAS interpreted this altitude bin change as the initiation of a climb by the intruder and projected that the intruder would now pass above the TCAS aircraft. The advisory selection logic determined that the greatest separation could be obtained at CPA by issuing a DESCEND advisory. When the intruder's reported altitude returned to its original value, TCAS projected that separation would no longer be provided on the predicted side (below in this case) of the intruder, and a TCAS Invalid advisory was issued.

When the altitude bin crossing occurred, the intruder had already satisfied the range tau criterion for issuing a Warning, but the vertical separation was such that the Warning was not issued. Once the bin crossing occurred, the TCAS confidence, or firmness, in the intruder's projected altitude decreased and its climb rate was projected to be in excess of 6,000 fpm. This projected climb rate satisfied the vertical tau criterion, and a Warning was issued with low confidence in the intruder's altitude rate. A change has already been incorporated in the TCAS II MOPS to delay issuing a Warning when the intruder's track firmness is low. MITRE simulations have shown that had this change been incorporated into the avionics used in this evaluation, this Warning would not have been issued.

## 5.2 TCAS WARNING 10

On April 15, 1987, Piedmont Flight 63 en route from Washington, D.C., was maneuvering for final approach in the Charlotte, North Carolina, terminal area. Flight conditions at the time were marginal VFR, with in-flight visibility approximately 3 miles in haze and a thunderstorm approaching the airport. Flight 63 was cleared for a visual approach to

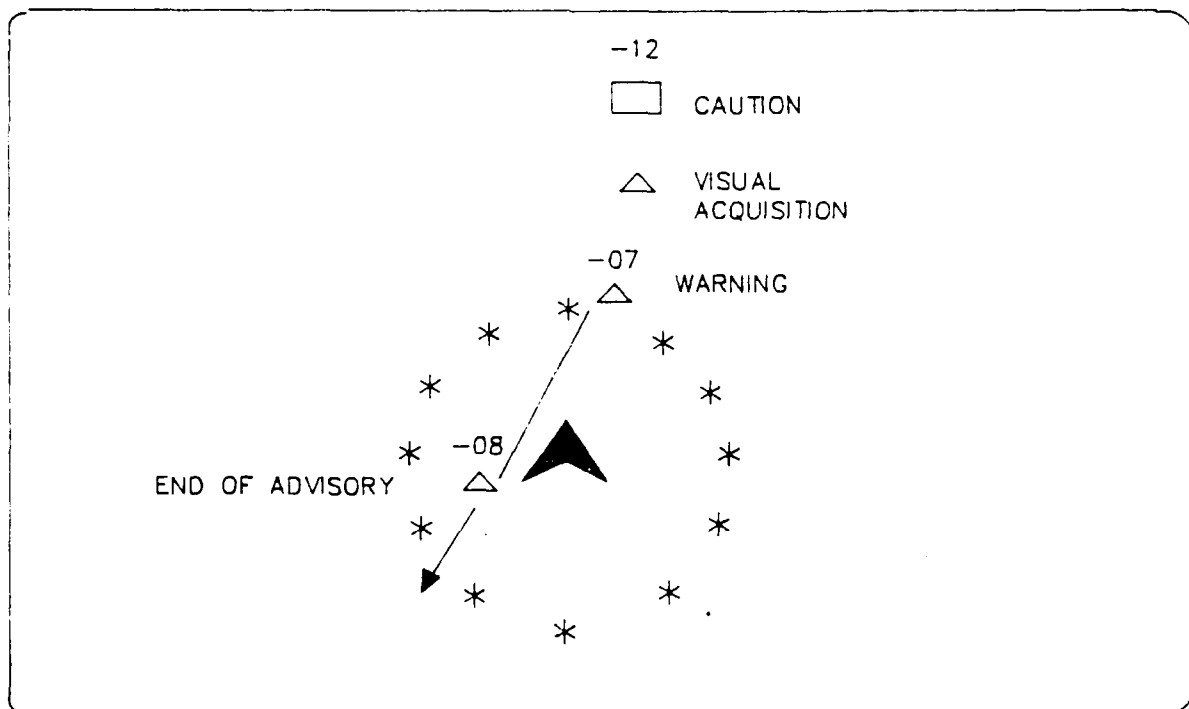
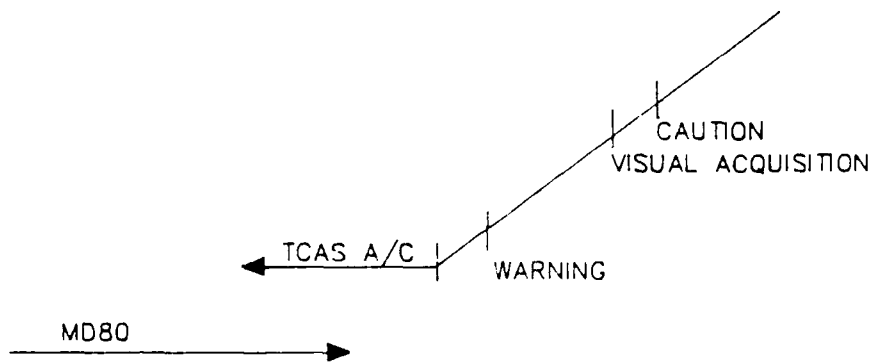


FIGURE 5-1  
OBSERVER DATA FOR WARNING 6

MC SIM RA

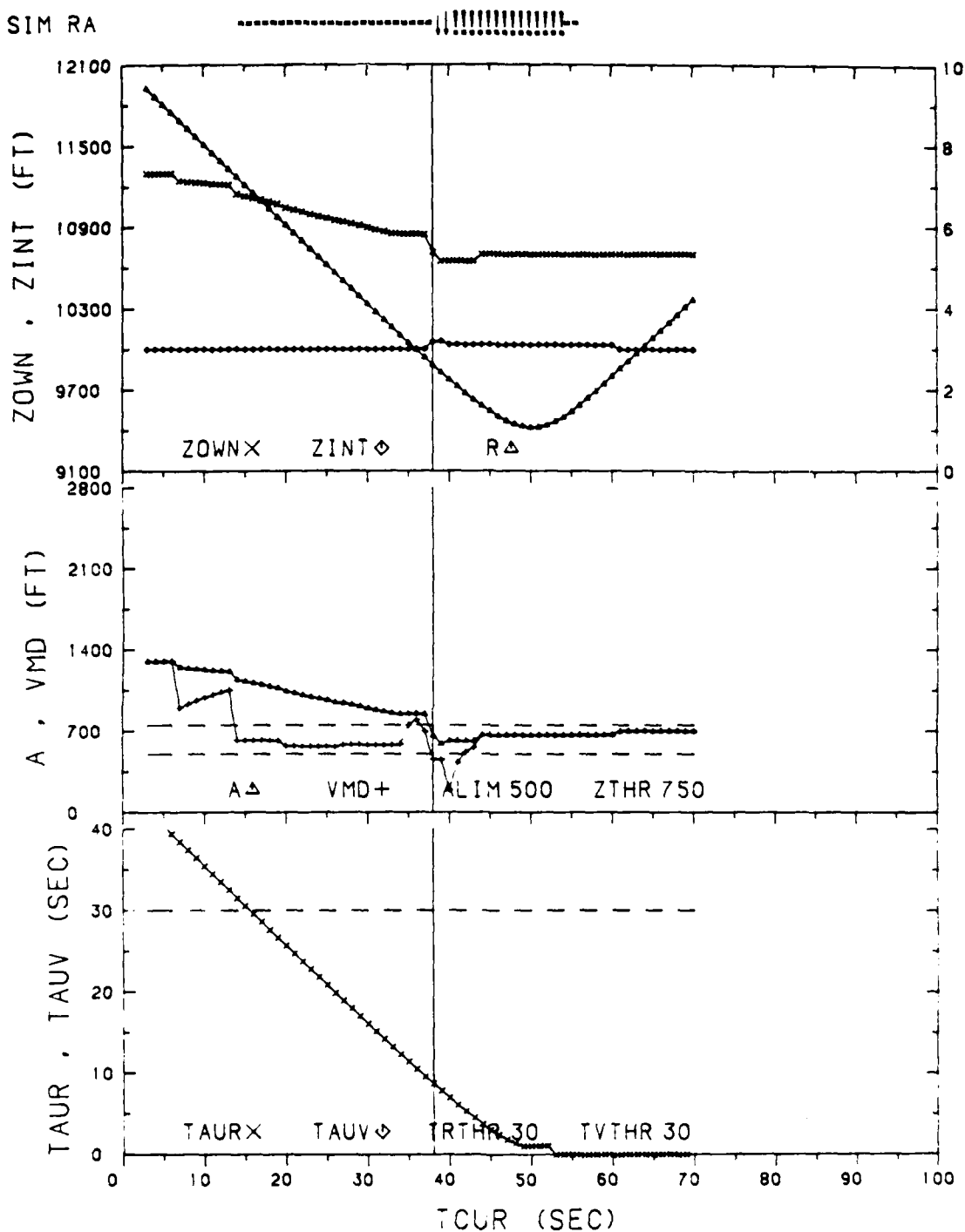


FIGURE 5-2

MITRE RECREATION OF WARNING 10

runway 36R and commenced a turn from base leg to final. ATC advised the crew of the traffic established on final approach for runway 36L. Within 5 seconds of the ATC advisory, TCAS generated a Caution showing the traffic at 12 o'clock, 300 feet below. The crew used the CRT information to visually acquire the intruder. A TCAS Warning followed, advising the crew to CLIMB. Immediately after the Warning, ATC again called with a notification that Flight 63 had flown through the final approach course for 36R and entered the No Transgression Zone (NTZ). Since the traffic was in sight and the crew was aware of its intentions, the Warning was not followed. Additionally, the pilots stated that responding to the CLIMB command would have more than likely resulted in a missed approach. Instead, the situation was resolved by initiating a turn to final, which removed the Warning.

Although this Warning occurred in a parallel-approach situation, the Warning was caused by the crew's failing to intercept the final approach course and entering the NTZ.

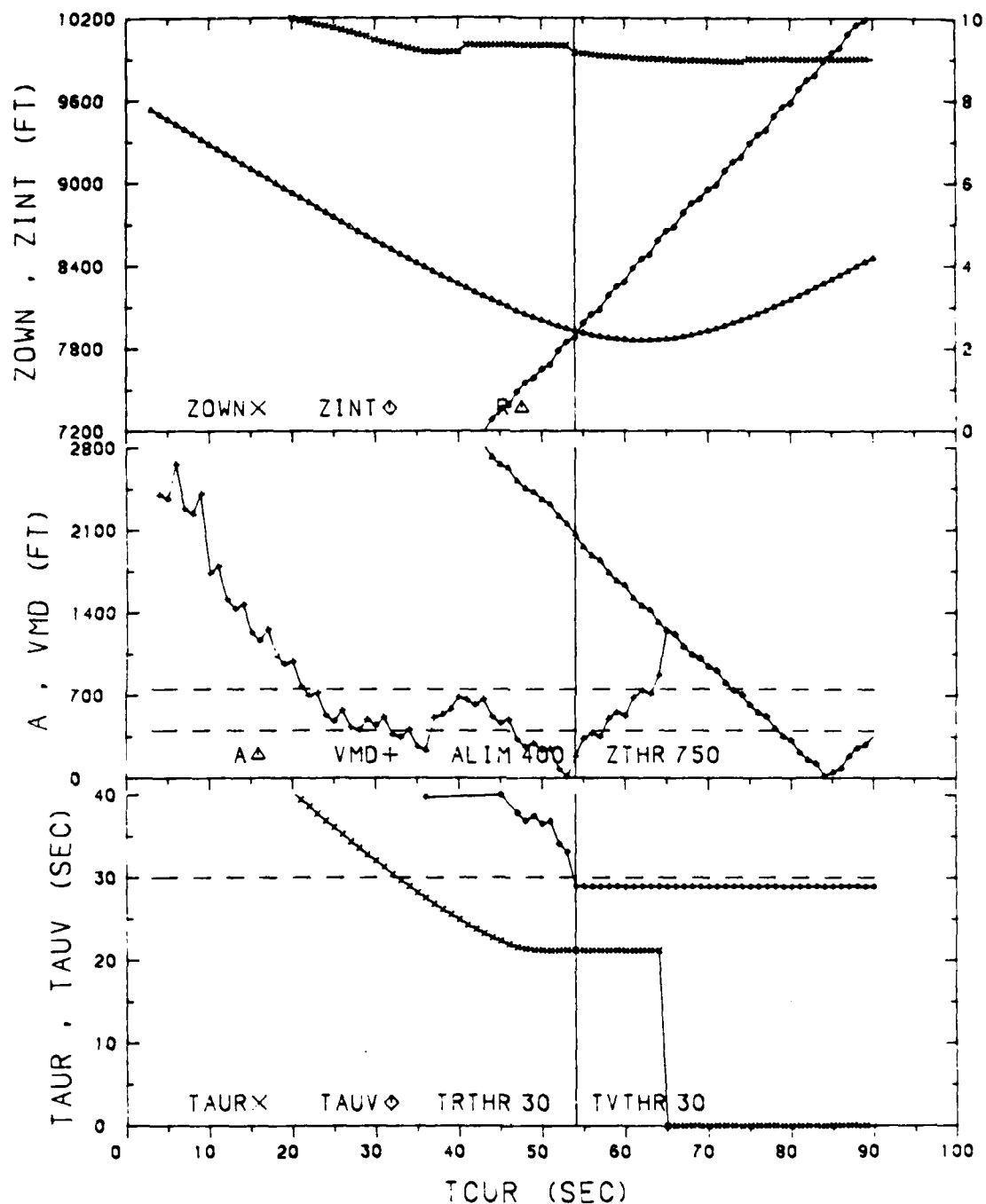
### 5.3 TCAS WARNING 11

Piedmont Flight 57 was en route to Tampa, Florida, from Baltimore, Maryland, on April 16, 1987. At 1804Z the aircraft was approximately 10 miles north of Tampa and level at 10,000 feet when a TCAS Caution was generated. The Caution showed the intruder aircraft at 12 o'clock, 2,100 feet below. Shortly after, ATC also advised Flight 57 of the traffic -- a B-737 departing TPA and crossing left to right. Flight conditions at the time were day, VMC, with 15 miles visibility. As the crew acquired the intruder visually, a DESCEND Warning was issued by TCAS. Flight 57 had been previously cleared by ATC to descend to 2,000 feet, but the pilot elected to maintain present altitude until after CPA, when the two aircraft began diverging. Visual separation was maintained throughout the encounter. The fact that the DESCEND advisory caused an altitude crossing situation and the observer questioned the advisory prompted additional analysis of this encounter.

As with Warning 6, no TCAS data were recorded for this encounter. However, ATC data tapes obtained from the Tampa TRACON enabled MITRE to recreate the encounter and analyze the performance of TCAS. The TRACON data included tracks for both the TCAS aircraft and the intruder aircraft, but the data points were provided every five to seven seconds instead of every second as they are provided by TCAS. Therefore, it was necessary to fill in the intermediate data points.

In this encounter, the TCAS aircraft's quantized Mode C altitude oscillated across a bin boundary and caused the Warning to be issued. This oscillation was between 10,000 feet and 9,900 feet, which TCAS interpreted as the beginning of a descent. The oscillation caused a decrease in the confidence in the projected vertical profile of the TCAS aircraft, so the Warning was selected on low firmness. TCAS projected that with the apparent descent initiated by the TCAS aircraft and with the intruder climbing, a DESCEND advisory would provide the greatest vertical separation at CPA. Figure 5-3 shows the geometry and vertical profiles for this encounter.

MC SIM RA



TAMPA

FIGURE 5-3

TAMPA TRACON DATA FOR WARNING 11

A change to the TCAS logic, which biases the logic against the issuance of such altitude crossing TCAS Warnings, has been developed by MITRE and will be incorporated into the MOPS.

#### 5.4 TCAS WARNING 12

On April 18, 1987, the TCAS aircraft, operating as Piedmont Flight 115, was 30 miles south of Grand Rapids, Michigan, en route from Dayton, Ohio. The aircraft was leveling off at its assigned altitude of 10,000 feet. The flight conditions were day, VMC, with visibility approximately 10 miles. There was a broken cloud layer just below 10,000 feet. At 1925Z, ATC advised the crew of traffic slowly climbing through 9,300 feet heading in the opposite direction. Almost immediately after the ATC advisory, TCAS generated an advisory showing an intruder at 11 o'clock, 1,000 feet below and climbing, at a range of approximately 2 miles. At a range of approximately 1 mile, TCAS issued a CLIMB Warning and showed the intruder at 10 o'clock, 500 feet below and climbing. Without visual contact (the intruder aircraft was below the cloud layer) the crew advised ATC that they had received a TCAS Warning and requested permission to "climb 200 or 300 feet." Since ATC cannot issue such a clearance, the flight was cleared to climb back to 12,000 feet and, as the aircraft climbed, the CLIMB command was downgraded to LIMIT VERTICAL RATE - DO NOT DESCEND. The advisory was removed when the intruder passed down the left side of the aircraft to the 7 o'clock position. Figure 5-4 and Figure 5-5 show the details of this encounter.

The ATC controller involved in the encounter later stated that Flight 115's request for a higher altitude could be accommodated because traffic was light and it was a Saturday afternoon. If this situation had occurred during a period of heavier traffic, there might have been an impact on the ATC system and the request might not have been honored. Since the intruder aircraft leveled off at 9,500 feet, the ATC-assigned altitude of 10,000 feet would have provided adequate, legal separation. Because the intruder was climbing at a low rate when the advisory was issued and the projected vertical miss distance at CPA was small, TCAS judged it was necessary to issue a CLIMB advisory to provide separation at CPA.

#### 5.5 POP-UP ENCOUNTERS

As discussed in Section 4.5.5, three Warnings were received without a precursor Caution. Data on one of the three encounters were recorded by the TCAS data recorder. These data are being reviewed by MITRE to determine why a Caution was not issued.

The data from the recorded encounter are shown in Figure 5-6. The intruder was a Navy C-12 (King Air) that was initially tracked at an unrealistic climb rate, with the result that the projected vertical miss distance at CPA was less than the separation considered adequate by TCAS. The data show no track data until approximately two seconds before the Warning was issued. By this time, the Warning criteria had been satisfied. The tracked climb rate was reinitialized to a more realistic value six seconds after the Warning was issued, causing the Warning to be removed within 5 seconds.



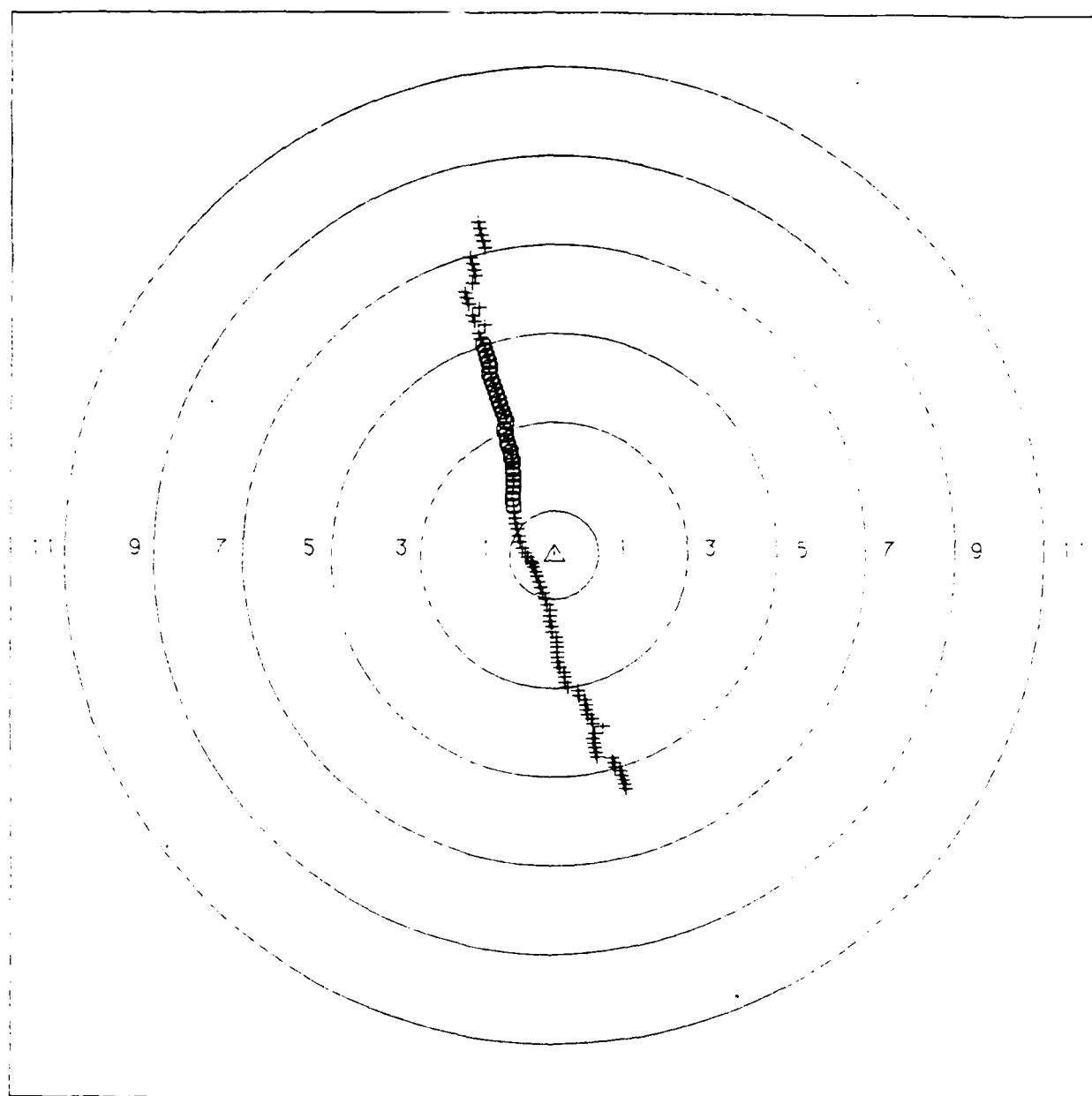


FIGURE 5-4

BEARING PLOT FOR WARNING 11

FLIGHT RA

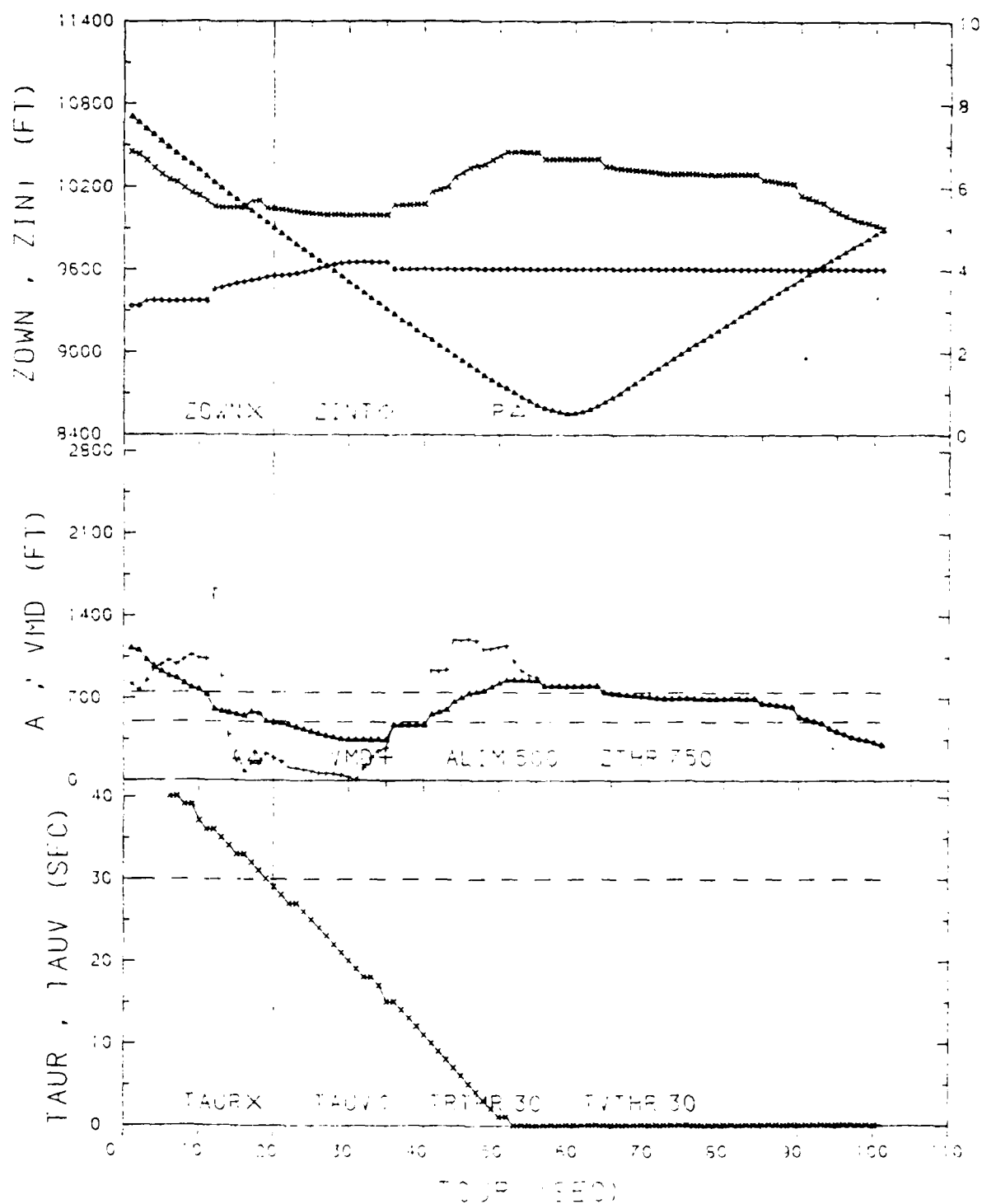



FIGURE 5-5

TCAS DATA FOR WARNING 11

FLIGHT RA   
 MC SIM RA

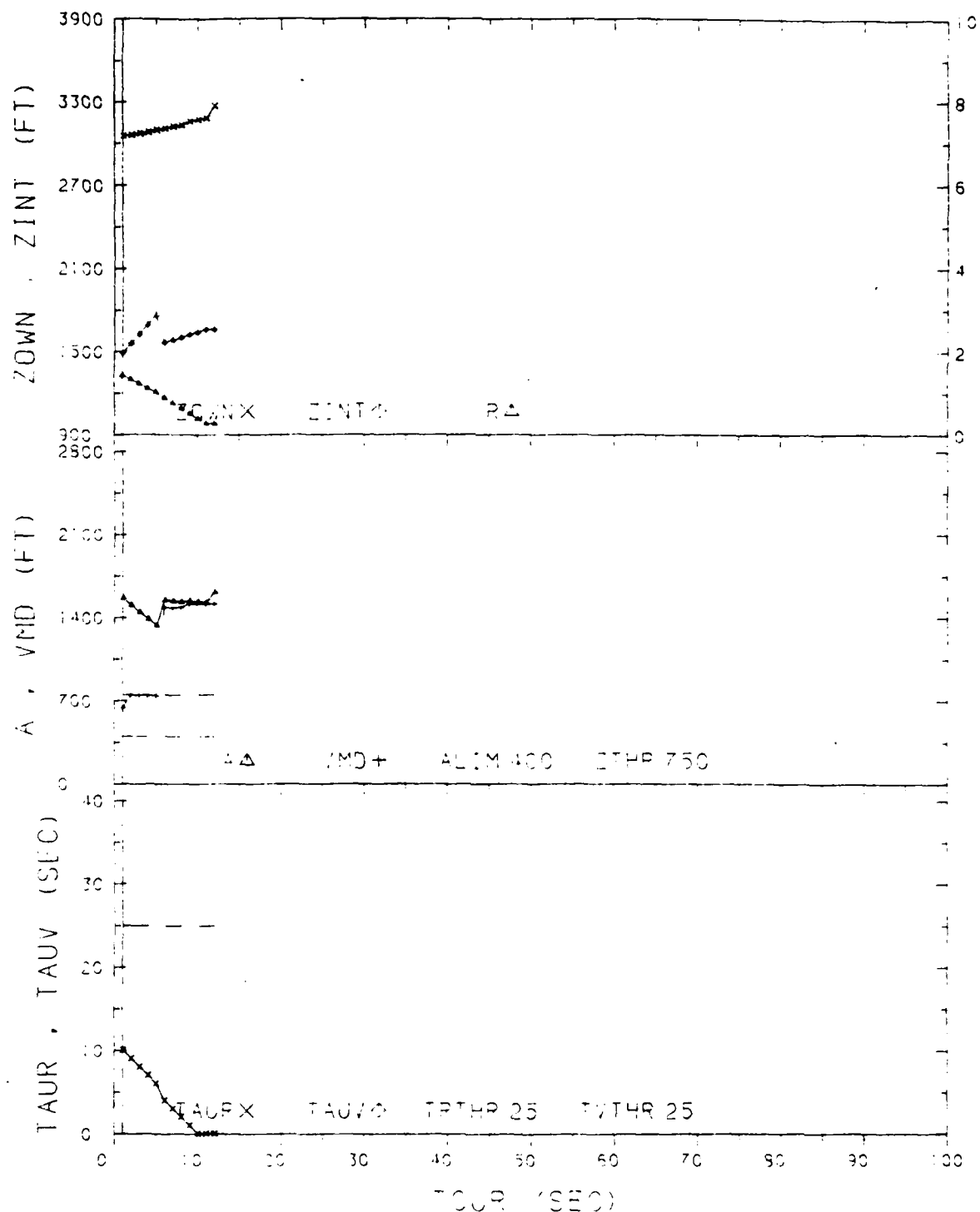


FIGURE 5-6

EXAMPLE POP-UP WARNING

## 5.6 PARALLEL-RUNWAY WARNINGS

Prior to the Phase II evaluation, concern was expressed about the impacts of using TCAS near an airport conducting parallel approach operations: when two aircraft are being turned on to the two parallel approaches, a TCAS Warning could be disruptive to the flow of traffic. During the evaluation, four of the 38 observed encounters involved parallel approaches. Three of the Warnings were corrective (see Section 4.4.10), and the advisory required that the existing descent be halted. The fourth Warning was a preventive advisory to DESCEND while the TCAS aircraft was descending. The DESCEND advisory was later weakened to DO NOT CLIMB after ALIM separation was achieved. In two of these encounters, CLIMB was the initial Warning; the initial DO NOT DESCEND advisory in another encounter was later strengthened to CLIMB.

Three of the four encounter geometries were different. Warning 10 and Warning 42 occurred with the TCAS aircraft turning final with the intruder established on final for the parallel runway. Warning 35 was a mirror image of these two Warnings; i.e., the TCAS aircraft was on final while the intruder was turning final. Warning 37 occurred with the intruder and TCAS aircraft simultaneously turning final. All four encounters occurred while visual approaches were being used. The intruder was visually acquired prior to the Warning in all cases, and the pilots did not follow the corrective advisory in any of the encounters. During the evaluation, no data were recorded that would permit an accounting of how often the TCAS aircraft was exposed to a parallel approach situation.

The data collected in Phase II are insufficient to address the industry's concern about parallel approaches. The data do confirm that TCAS Warnings can occur during such approaches. There were no observed instances of Warnings being issued while simultaneous ILS approaches were being made. However, Cautions were observed during simultaneous ILS approaches. Because of an ATC requirement to separate aircraft vertically in simultaneous ILS approaches, the probability of receiving a Warning during such operations should be lower than when visual approaches are in use.

## CHAPTER SIX

### AVIONICS AND OPERATIONAL ANOMALIES

The quantitative and qualitative data described in Chapter Four indicate that the TCAS II industry prototype performed as designed throughout the Phase II evaluation. The real-time performance monitoring software detected several avionics hardware problems that required removal of the avionics. All repairs to the avionics were performed by Dalmo Victor. (The details of these maintenance activities are described in Appendix E.) No software coding or logic errors were detected during the evaluation. However, several avionics and operational anomalies were noted, and these should be corrected in future implementations. While none of these anomalies exposed the TCAS aircraft to an unsafe flight condition, they did cause some confusion or distraction to the crew.

#### 6.1 INTERROGATION OF SHIPS

On twelve departures from Norfolk International Airport and three departures from Jacksonville, Florida, numerous (more than five) non-altitude reporting, "No Bearing" intruders were simultaneously displayed. Each intruder caused a Caution to be issued at a different time, resulting in a great deal of noise and confusion in the cockpit. The confusion was caused by the aural alarms generated by TCAS for each Caution and the frequent changing of an intruder's status from a Proximate display (blue) to a Caution display (amber) on the CRT. The confusion was compounded by the crew's uncertainty about where to look for the traffic, since the range was the only information available for each intruder. Another factor contributing to the confusion was the momentary availability of the bearing data on one or more intruders, which allowed the CRT display to show the relative bearing of the intruder only briefly.

An investigation of the anomaly identified the intruders causing these displays as U.S. Navy ships anchored at the Norfolk and Mayport Naval Bases. Any Navy or U.S. Coast Guard vessel longer than 54 feet is equipped with an Identification, Friend or Foe (IFF) that responds to the Mode C interrogation pulse transmitted by TCAS. The Navy's normal procedure is to turn the IFFs off while the ships are in port, but this practice is often not observed. This was confirmed by conversations with the FAA's facility chief at the Norfolk International Airport control tower, who reported that the airport's ground radar also interrogates the

ships' IFF, sometimes presenting a major problem for the controllers because of the clutter on their displays.

Because the ships are anchored and have zero velocity, the tau criterion for issuing a Caution was generally not satisfied until the TCAS aircraft was nearly directly above of the ships. As a result, the IFF replies were received only on the bottom, omnidirectional antenna.

The ships replying to the TCAS interrogations were anchored just off the departure end of runway 5 at Norfolk and near Chambers Field, NAS Norfolk, which is approximately 4 nm northwest of the airport. The ships in Jacksonville were located southeast of the airport at the Mayport Naval Base. However, TCAS will display non-Mode C intruders whenever the TCAS aircraft is operating below 15,500 feet MSL which may result in a display of this type of Caution whenever a TCAS equipped aircraft overflies a naval base. Although this anomaly may be observed at only a limited number of locations (Norfolk, Virginia; Jacksonville, Florida; San Diego, California; San Francisco, California; Philadelphia, Pennsylvania; Charleston, South Carolina) and crews could be trained to expect ships being displayed in these areas, there is some risk associated with countering this anomaly by training. If the crews begin to expect that ships are causing the non-Mode C Cautions near these airports, they may become complacent and fail to scan visually for the traffic and thus may not see a non-altitude reporting aircraft operating near the naval bases.

In response to the problem, MITRE has proposed a change to the TCAS logic that will inhibit the display of Cautions against non-altitude reporting intruders without bearing information available. The modification should eliminate most of the displays caused by ships.

The investigation of this anomaly revealed that the IFFs have the capability to report altitude. The altitude reporting is controlled by a switch that Navy operating procedures allow to be in either the ON or OFF position. In addition to implementing the logic modification recommended by MITRE, the Navy should be requested to enable the altitude reporting capability of the ship's IFF. This would allow TCAS to use its vertical separation criteria to determine that the ships are not potential threats, thus preventing the display of ships except when a TCAS-equipped aircraft is operating at low altitude near a Navy facility.

## 6.2 SHORT DURATION CAUTIONS

Numerous encounters were observed in which a Caution was displayed for a very short period. As shown in Figure 6-1, 65 Cautions (9 percent) are displayed for less than five seconds and 159 (22 percent) are displayed for less than eight seconds. These short duration displays are a nuisance and distraction to the flight crews and may diminish confidence in the system. The major problem with having Cautions displayed for a short period is that the crews do not have sufficient time to recognize that a Caution is being displayed and interpret the

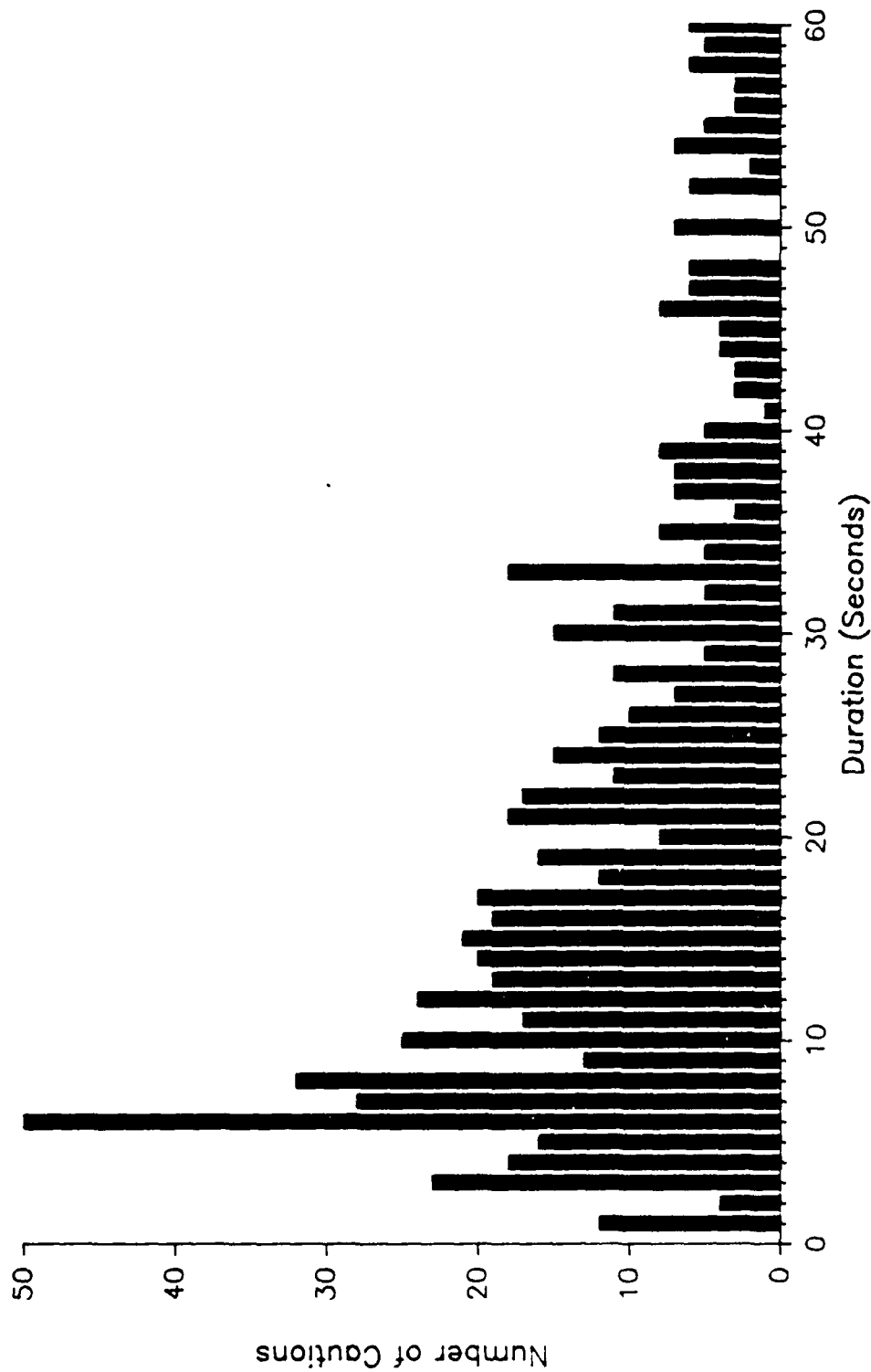


FIGURE 6-1  
DISTRIBUTION OF TCAS CAUTION DURATION (ALL CAUTIONS)

data before the display is cleared. By the time the aural annunciations are completed and the crew looks at the display to determine the location of the intruder, the display is blanked.

The observers noted that most of the short duration Cautions were issued against non-Mode C intruders. The data shown in Figure 6-2 confirm this observation. Forty-seven of the 65 encounters (72 percent) with a duration less than five seconds and 117 of the 159 encounters (74 percent) with a duration less than eight seconds were caused by non-Mode C equipped intruders.

The current TCAS display logic provides for displaying a Caution for a minimum of eight seconds. However, this assumes that the surveillance portion of the system is providing the CAS logic with an updated track on the intruder. If the surveillance logic drops a track, the intruder will no longer be displayed on the CRT. A review of the recorded data for these advisories indicate that the short duration Cautions are a result of the non-Mode C surveillance passing the intruder to the CAS tracker on a range coast where it is declared a threat. Once the CAS logic declares an intruder a threat, a Caution is displayed to the crew. If replies are not received from the intruder for three consecutive interrogations, the surveillance logic drops the intruder's track which results in CAS also dropping the intruder as a threat. When this occurs, the displayed information is removed. MITRE is in the process of developing a modification to the TCAS logic that will prevent the issuance of a non-Mode C Caution on a range coast. This modification should eliminate this type of advisory.

### 6.3 DISPLAY OF CAUTIONS AT LOW ALTITUDE

The display of Cautions during operations at low altitudes (lower than 1,000 feet AGL) was a major distraction during the Phase II evaluation, especially when the Caution was issued immediately after take-off while the aircraft was at an altitude lower than 200 feet AGL. During the evaluation, 85 Cautions (12 percent) were issued while the TCAS aircraft was below 1,000 feet and 46 Cautions (6 percent) were issued while it was below 500 feet. As with the short duration Cautions, a major contribution to this anomaly was the presence of non-altitude reporting aircraft. Figure 6-3 indicates that 49 of the 349 Cautions issued against non-altitude reporting intruders occurred while the TCAS aircraft was operating below 1,000 feet. These represent 58 percent of the total Cautions issued below 1,000 feet.

As previously stated, the display of traffic information immediately after departure is a major distraction to the crew. The departure is a time of high workload and intense concentration in the cockpit, and the presentation of any non essential information to the crew is a distraction. This is especially true when the information display is accompanied by a loud aural annunciation and the illumination of a glareshield light. In several of the Cautions issued against non-Mode C



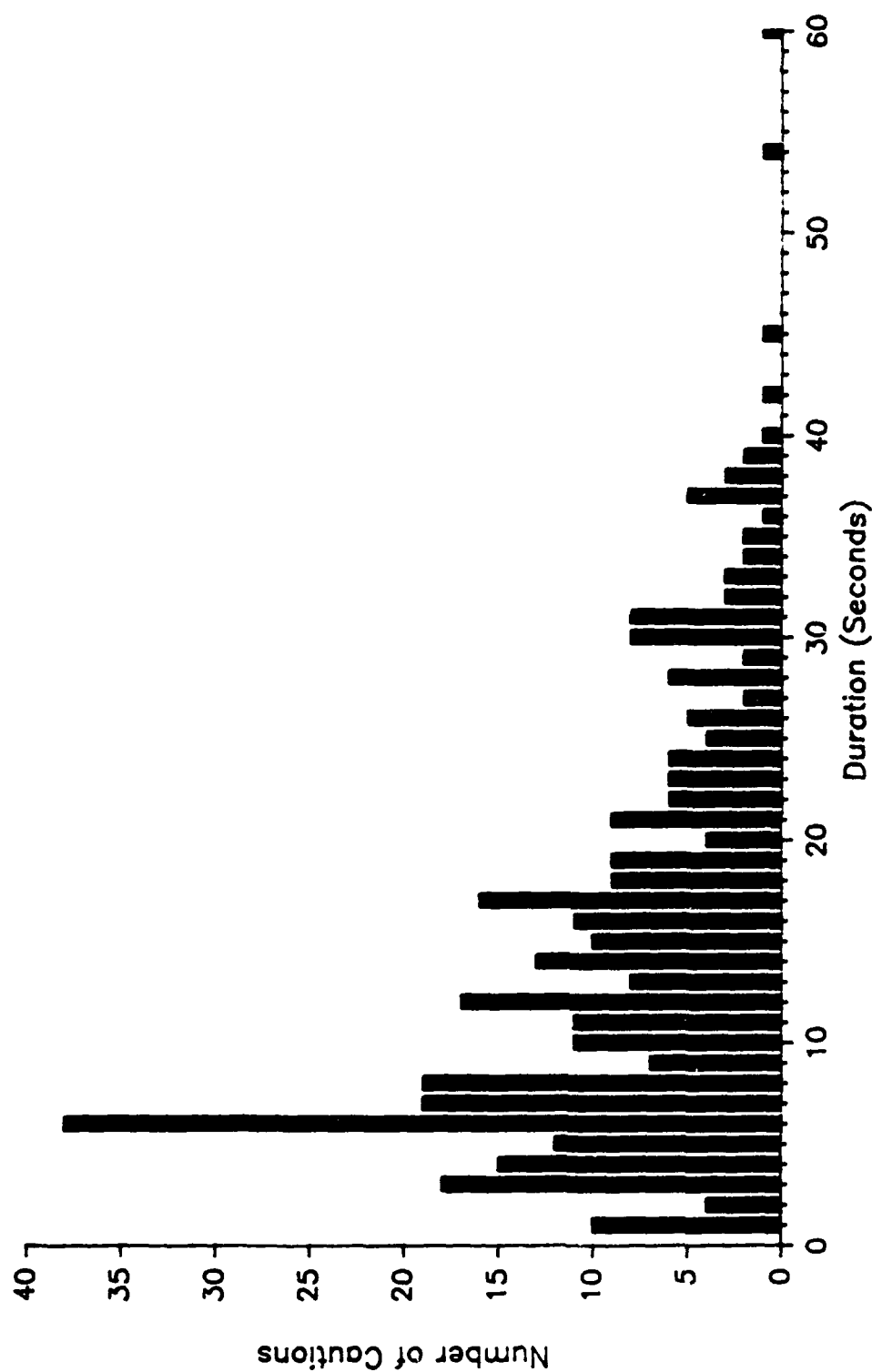


FIGURE 6-2  
DISTRIBUTION OF NON-MODE C CAUTION DURATION

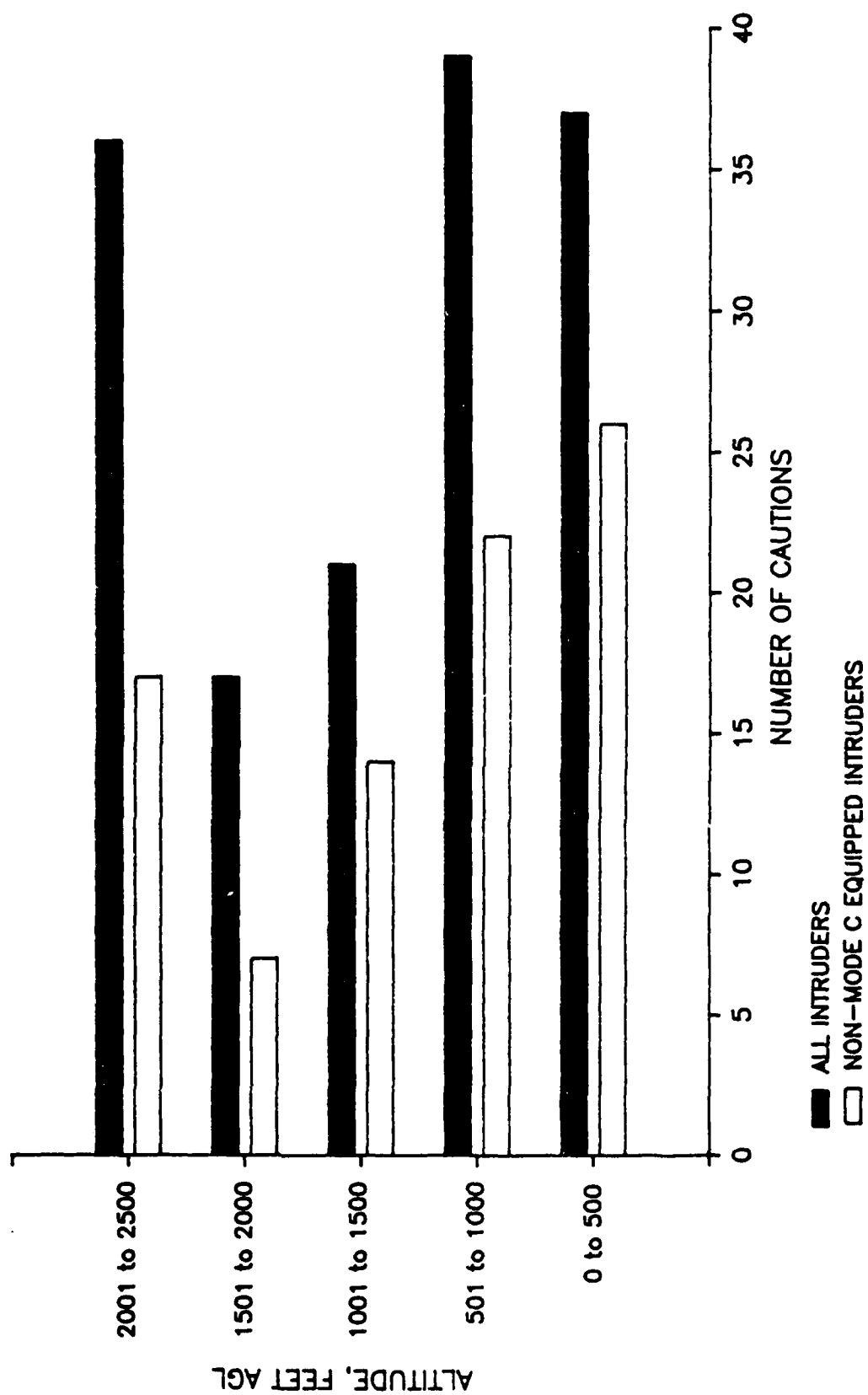


FIGURE 6-3  
TCAS AIRCRAFT ALTITUDE WHEN CAUTION IS ISSUED

equipped aircraft, the intruder aircraft was determined to be an aircraft taxiing near the departure runway. Without an altitude reporting transponder, there is no way for TCAS to determine if the intruder is on the ground or in the air.

Mode C equipped intruders on the ground are not displayed, because the Aircraft-on-Ground logic determines that the intruder is on the ground. The Aircraft-on-Ground logic was added after the Phase I evaluation to eliminate the display of intruder aircraft on the ground. The results of the Phase II evaluation demonstrate that this logic is effective against altitude reporting intruders. There is additional logic in the Phase II avionics that eliminates the problem during arrivals by inhibiting all displays when the TCAS aircraft is in the landing configuration and below 1,000 feet AGL. The removal of this logic for future implementations may result in the issuance of additional Cautions against non-Mode C aircraft during operations at low altitude. In fact, the distraction may be greater during the arrival, because the geometry dictates that the TCAS aircraft will typically be less than one mile from landing when the 20 to 25 second tau criterion is met. On the basis of the existing Aircraft-on-Ground logic, it is safe to assume that the five Cautions issued against altitude reporting intruders during operations below 500 feet represented airborne aircraft that were potential threats. One observed case was caused by an intruder that departed from a parallel runway at the same time as the TCAS aircraft.

Below 500 feet AGL, TCAS is in Sensitivity Level two (SL2), and the CAS logic allows the user to determine if the display of Cautions is desired in SL2 by setting the P. LOWTA flag TRUE in the Update Advisory Mode. If the flag is set TRUE, Cautions will be displayed in SL2. Until all aircraft become Mode C equipped, the only solution is to eliminate the display of non-Mode C traffic while TCAS is in SL2. A less restrictive logic modification would be to eliminate the display on non-Mode C Cautions while in SL2 only after departure, which was the flight phase where the distraction was the greatest. This change will eliminate most of the distractions caused by displaying Cautions at low altitudes. The remainder of the Cautions displayed at low altitudes will be caused by airborne, altitude reporting aircraft that represent a potential threat to the TCAS-equipped aircraft.

It is also recommended that crews be given the capability to display traffic, using the TCAS/TRACKS mode, while their aircraft are on the ground. With this capability, a crew could view the traffic in the vicinity of the departure runway before initiating the take-off roll, minimizing the distraction if a Caution is issued during departure.

#### 6.4 WARNINGS ISSUED AT CPA

Three Warnings were issued just before the range between the TCAS aircraft and the intruder aircraft started to diverge. The observers and several representatives of the evaluation team considered the Warnings unnecessary and a nuisance. (It should be noted that the crews did not consider two of the Warnings a nuisance and were glad to have the information available. The third Warning was considered unnecessary by the crew.)

To eliminate these types of advisories, MITRE has designed a Nuisance Alarm Filter for the TCAS II logic. It will prevent the TCAS logic from issuing a Warning against threats whose range tau (TRTRU) has begun to rise and whose range exceeds 1.5 nautical miles. The operation of the filter is illustrated in Figure 6-4, which shows true range tau (TRTRU) versus range. As an intruder aircraft converges with the TCAS aircraft, the value of TRTRU decreases. When this value drops below the range tau threshold, it is said to have satisfied the range criterion for issuance of a Warning. At any time thereafter, if the vertical separation of the two aircraft falls below the altitude threshold (ZTHR), a Warning will be issued.

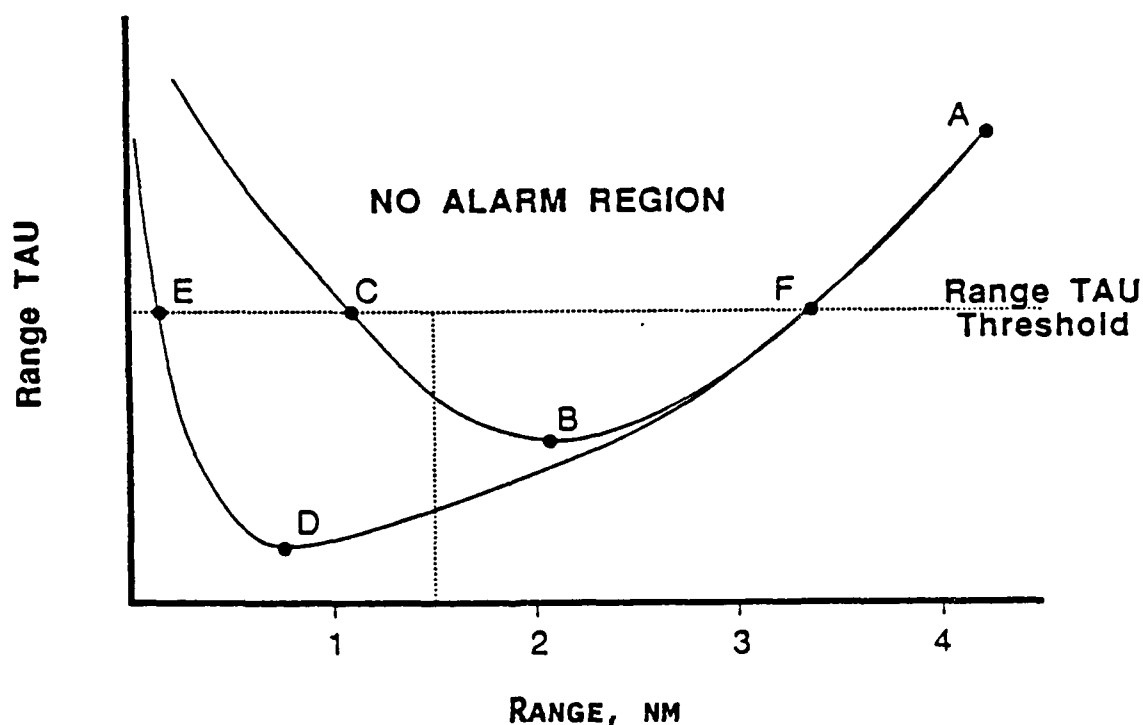


FIGURE 6-4  
RANGE VERSUS RANGE TAU FOR NUISANCE ALARM FILTER

The curve AFBC in Figure 6-4 is representative of an encounter with an intruder aircraft whose range tau begins to rise when it is separated from the TCAS aircraft by 2 miles. This encounter situation will result in a Warning if the altitude criterion is satisfied any time after the curve crosses the range tau threshold (at point F). However, if the altitude criterion is satisfied at point B or later, the relative bearing

of the intruder aircraft will be  $\pm 45$  degrees or more. Any Warning issued after this point can be said to be a nuisance. The Nuisance Alarm filter was designed to recognize that fact and will prevent issuance of a Warning in this instance. In a situation where the two aircraft pass very close in range (curve AFDE) before the range tau rises, a Warning will be considered necessary and will be issued to the crew.

#### 6.5 VOLUME OF AURAL ALARM

The aural alarm portion of the TCAS avionics provides a single volume for all flight conditions. The aural tones and words are generated within the TCAS computer unit and transmitted to a dedicated speaker mounted in the overhead panel. While the clarity of the aural annunciations was considered acceptable under all flight conditions, the volume of the aural tones was too loud for certain conditions.

When the level of ambient noise in the cockpit was low, the volume of the TCAS annunciations was too high. The cockpit noise level was typically low when the airspeed was low. Thus, during the initial climb segments and during descents below 10,000 feet, a Caution often startled the crew because of the loudness of the aural tones. At higher speeds, which produced higher ambient noise levels, the volume was comparable to that of other cockpit warning systems. To minimize the cockpit noise, it is desirable to include an ambient noise monitor with future TCAS installations. This monitor would permit setting the gain of the audio amplifier to different levels as the flight conditions and cockpit noise levels changed.

## CHAPTER SEVEN

### CONCLUSIONS AND RECOMMENDATIONS

The Phase II evaluation with the TCAS II Industry Prototype has made significant contributions toward the implementation of an effective airborne collision avoidance system. The use of the TCAS II Industry Prototype in 828 observed hours of operation has demonstrated that the present design of TCAS is an effective supplement to the see-and-avoid concept of collision avoidance and an excellent backup to the separation services provided by ATC. The evaluation has also demonstrated that trained flight crews can use the TCAS displayed information in the desired manner without being distracted from their other cockpit tasks. The crews using the system provided numerous suggestions for improving the design and utility of TCAS.

The Phase II evaluation has demonstrated the utility and effectiveness of TCAS in its intended operational environment and has identified design parameters that should be modified to improve its effectiveness. This chapter summarizes the findings of this evaluation and present recommendations for future TCAS implementations.

#### 7.1 IMPACTS ON CREW WORKLOAD

TCAS did not have a significant impact on crew workload. The crews demonstrated the ability to integrate the TCAS-related tasks with other cockpit activities and with traffic information available from other sources. They were able to assign proper priorities to the displayed TCAS data so that TCAS did not distract them from higher priority tasks. When necessary, the crews delayed using the TCAS displayed data, especially Cautions, until they had finished other cockpit tasks and then began a visual search for traffic.

No quantitative data on crew workload were collected during this evaluation. The assessment of TCAS impact on a crew's workload was based on comments received from the Piedmont crews and the qualified cockpit observers.

## 7.2 IMPACTS ON ATC

TCAS had no significant impacts on the ATC system during the Phase II evaluation. The observers and flight crews reported no unusual handling of the TCAS aircraft, and there were no reported requests from the crews for special handling. With only one TCAS equipped aircraft operating in the NAS, the data acquired are insufficient for determining if widespread use of TCAS will have any impacts on ATC. Additional data, obtained with more than one TCAS equipped aircraft operating in the NAS, are necessary for a full assessment of the impacts of TCAS on ATC.

Only two of the TCAS Warnings issued during the evaluation resulted in deviations from assigned ATC altitudes; one deviation being approximately 200 feet and the other approximately 300 feet. Numerous Warnings resulted in changes to the aircraft's climb or descent profile. All deviations from an assigned altitude and all changes in climb and descent profiles were transparent to the controller working the aircraft. There were no reports of an impact on an individual controller from a crew's response to a TCAS Warning.

## 7.3 EFFECTIVENESS OF TRAINING PROGRAM

The flight crew training program used in the Phase II evaluation was effective in teaching the crews how to respond to a TCAS Warning and return to their original clearance, while minimizing deviations from the original clearance. The program was also effective in training the crews to interpret the IVSI display and most of the information displayed on the CRT. The crew's responses to TCAS Warnings were timely, smooth, and of the proper magnitude. No observed responses caused excessive deviations from the original clearance or the use of higher vertical rates than required.

There was some confusion about the meaning of intruder displays in the "No Bearing" table on the CRT. Some crews did not realize that an intruder without bearing information available could cause a Caution to be issued. The meaning of the "No Bearing" display should receive increased emphasis in future training programs.

Future training programs should also emphasize any changes to the operation of other cockpit systems resulting from the installation of TCAS. The modification to the weather radar indicator resulted in a nonstandard operating configuration for the TCAS aircraft. Even though this was addressed in the training program and the TCAS Operations Manual Supplement, there was a great deal of confusion about the interface between TCAS and the weather radar.

The Phase II training program consisted of a video tape presentation, a review of the Operations Manual material by an instructor, and a quiz to verify a pilot's understanding of TCAS. Although the crews and observers said that this approach was acceptable, comments from observers and pilots indicated that hands-on training would increase crew knowledge

of the system. None of the comments received indicated that hands-on training was required for safe operation of the system.

A number of crews had detailed questions about system design parameters such as interrogation range, update rate, and maximum number of aircraft tracked. This information was intentionally omitted from the training program because it was not necessary for operating the system. To ensure that interested pilots can locate such information, a detailed technical description of TCAS should be available.

#### 7.4 DISPLAY INTERPRETATION

Only one problem with understanding or interpreting the IVSI or CRT displays was observed. It was caused by a lack of complete understanding by some crews of the "No Bearing" display on the weather radar CRT. These crews' confusion was increased when a non-altitude reporting intruder was displayed with no bearing information available. Increased training emphasis on the "No Bearing" display (see Section 7.3) and the proposed elimination of the display of non-altitude reporting, "No Bearing" intruders should eliminate this interpretation problem. The proposed change to the MOPS should be implemented in future TCAS designs.

The IVSI was proven to be an effective means of displaying TCAS Warning information in a conventional (non-glass) cockpit. Neither the crews nor the observers recommended any changes to the IVSI.

Similarly, no changes were recommended for the CRT display. The crews considered the displayed information adequate to assist them in visually acquiring nearby aircraft. No changes in the amount and type of data displayed on the CRT were recommended. The colors and symbology used on the CRT were acceptable to all crews participating in the evaluation.

#### 7.5 ADVISORY RATES

The advisory rates experienced in the Phase II evaluation were higher than the rates experienced in previous TCAS evaluations. A TCAS Caution was received every 1.8 flight hours, and a TCAS Warning was received every 22.4 flight hours. There were no adverse crew reactions to these advisory rates.

The Phase II evaluation marked the first time non-altitude reporting aircraft were tracked by TCAS. Forty-eight percent of the Cautions received were caused by non-altitude reporting aircraft.



## 7.6 AVIONICS PERFORMANCE

The TCAS avionics hardware and software performed as designed throughout the evaluation. Several hardware failures requiring return of the avionics to the manufacturer for repair were detected. No software errors (coding or design) were detected during the evaluation.

All the hardware problems were detected by the avionics real-time performance monitor software, and all of them were caused by failed components within the Computer Unit or Bearing Electronics Unit. None of these problems required a design change to the avionics hardware.

## 7.7 VISUAL ACQUISITION

A major benefit of the TCAS CRT display is assisting a crew in visually acquiring nearby or threat aircraft. During the Phase II evaluation, 63 percent of the altitude reporting intruders and 20 percent of the non-altitude reporting intruders causing a Caution were visually acquired by the crew. Visual acquisition using the TCAS information often occurred when a crew had been unable to acquire the traffic after an ATC advisory. The correlation between the displayed position of the intruder and its actual position was excellent throughout the evaluation. In order for the users to realize the full utility of TCAS, it is necessary to increase the number of general aviation aircraft equipped with an altitude reporting transponder.

## 7.8 USE OF TCAS/TRACKS MODE

The Industry Prototype avionics provided a crew with a momentary display (15 seconds) of nearby aircraft. The training program and Operations Manual did not define specific procedures for using the TCAS/TRACKS mode, and the use of that mode therefore varied from crew to crew. Some crews never used it, while others made extensive use of it, especially in the terminal area. Because of this difference in usage, it was impossible to develop a consensus on how this feature should be implemented in future installations.

Mixed views were expressed regarding the utility of this display mode. Some crews thought that the display could become a distraction, while some considered its momentariness the only distraction and expressed a desire for a full-time display. There was near unanimous agreement among the crews using this display mode that the display parameters of  $\pm 1,200$  feet and 4 nm were too restrictive, especially at cruise altitudes and speeds.

The TCAS/TRACKS mode was used in all phases of flight. However, it was used most frequently following an ATC traffic advisory, during maneuvers in the terminal area, during visual approaches, and after the discontinuation of a Caution or Warning. The TCAS/TRACKS mode is beneficial to a crew, and there were no observations of its being used to increase separation from displayed traffic.

For future installations, the TCAS/TRACKS mode should be retained. The implementation should allow a pilot to select a full-time or momentary display. It should also provide push buttons rather than a rotary switch for selecting the momentary display -- a button for each crew member, preferably on the control yoke, to facilitate selection. The crew should also have a means of independently selecting the display parameters, i.e., range and altitude.

## 7.9 AURAL ANNUNCIATIONS

There were no observed misunderstandings of the aural annunciations (tones or spoken words) used in the Phase II evaluation. The crews considered the aural annunciations an essential part of the system.

The volume of the aural annunciations was acceptable except when the ambient noise level in the cockpit was low. In those cases, the annunciation volume was too high and often startled a crew. Future avionics designs should include an ambient noise monitor in the cockpit that controls the gain of the audio amplifier used to drive the aural annunciations.

The terminology used in the spoken words and phrases is acceptable to the pilots. It is recommended that an additional phrase be added to alert the crew that the Warning has been removed. This phrase is needed only when a crew has silenced the aural annunciation provided with each Warning. If the aural is not silenced, removal of the aural when the advisory is removed should provide sufficient notification.

Additional simulator studies should be performed to assess the feasibility of eliminating some of the aural annunciations while the aircraft is operating at low altitudes. The information displayed on the IVSI and CRT is desired by the crews when they are operating at low altitude, but they think that the noise caused by TCAS is excessive. These analyses should investigate using either the European siren alone or the spoken words and phrases alone in a high-workload environment.

## 7.10 SHORT DURATION CAUTIONS

Only more than nine percent of the Cautions issued during the evaluation were displayed for less than five seconds. Of these, 72 percent were caused by non-Mode C equipped intruders, and they were a nuisance and a major distraction to the crews. When a Caution is displayed for less than five seconds, the crew does not have enough time to hear the aural, recognize it as a TCAS advisory, look at the CRT, and determine the intruder's position. In a number of these Cautions, the CRT was blank by the time the crews looked for the information. In addition to being a distraction, such advisories reduce the crew's confidence in the system and create doubt about whether it is functioning properly.

These short duration advisories must be eliminated in future TCAS systems. If an advisory is displayed to the flight crew, it must remain displayed long enough to be interpreted. It is recommended that the non-Mode C surveillance and tracking algorithms be modified to ensure that TCAS has a high degree of confidence in the intruder's track before it issues a Caution. If confidence in the intruder's track is low, the Caution should be delayed until it is higher. An alternative to this approach is to modify the display logic to ensure that once a Caution is displayed, it remains displayed for a minimum of five seconds regardless of the intruder's track firmness.

#### 7.11 LOW ALTITUDE DISPLAY OF TRAFFIC

Forty-six Cautions were issued while the TCAS aircraft was at or below 500 feet, with 27 being caused by non-altitude reporting aircraft. Some of the Cautions occurred immediately after take-off. Low-altitude Cautions occur in a high-workload environment, and the aural alarm is a major distraction. Although the crew performed a visual search, only a small percentage of intruders were visually acquired. When the intruder aircraft was sighted, it was often an aircraft taxiing near the departure runway. Without the altitude information provided by an encoding altimeter, there is no way for TCAS to determine that the aircraft is on the ground.

The display of traffic at low altitude is a major distraction, and most of the low altitude Cautions are caused by non-Mode C equipped aircraft. It is recommended that Cautions not be displayed for these intruders while a TCAS equipped aircraft is below 500 feet. This change would greatly diminish the problem and should eliminate nuisance Cautions. A more drastic solution is to inhibit the display of all traffic below 500 feet. This is unnecessary, however, since TCAS can determine when Mode C equipped aircraft are in the air and thus represent a potential threat.

It is also recommended that crews be given the capability to display traffic, using the TCAS/TRACKS mode, while their aircraft are on the ground. With this capability, a crew could view the traffic in the vicinity of the departure runway before initiating the take-off roll, minimizing the distraction if a Caution is issued during departure.

#### 7.12 INTERROGATION OF SHIPS

In operations near the Norfolk International Airport, numerous "No Bearing," non-altitude reporting intruders were simultaneously displayed. The number of targets shown on the CRT in a short period and the aural annunciations associated with the Cautions made these displays a major distraction. An investigation revealed that these intruders were IFF-equipped U.S. Navy ships anchored in the Norfolk harbor. The IFFs respond to the TCAS Mode C interrogations.

As discussed in Section 7.4, a change to the TCAS logic has been proposed to eliminate the display of non-altitude reporting aircraft when no bearing information is available. Since a majority of the ships detected have been displayed in the "No Bearing" table of the CRT, this proposed change should eliminate most of these displays. However, some ships' replies were received by the directional antenna, and so bearing information was available for a small number of ships. To eliminate the problem completely, it is recommended that the Navy be informed of this problem, be requested to reemphasize its policy of not operating the IFF while ships are in port, and be requested to specify that the altitude reporting capability of the installed IFFs be used at all times.

#### 7.13 INSTALLATION CONCERNS

Several problems with equipment location were noted during the evaluation. The Caution/Warning lights were suspended beneath the glareshield and blocked the captain's and first officer's views of two engine instruments. The lights should be mounted either in the glareshield or on the instrument panel. The location should allow the pilots to see the lights with peripheral vision while looking outside the cockpit.

The Caution/Warning lights' intensity was too high for night operations, and there was no way to dim these displays. A means should also be provided to control the lighting intensity of all TCAS instruments and controls.

Consideration should be given to modifying the frequency of the chime used to alert the crew to a Caution. Several comments received during the evaluation indicated that the TCAS chime sounded too much like the altitude alert chime.

APPENDIX A

FLIGHT CREW TRAINING MATERIAL

A.1 OPERATIONS MANUAL SUPPLEMENT

**EFFECTIVITY:** All B-727 Crews

**SUBJECT:** TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS)

**REASON:** This bulletin provides information on the procedures to be used by Air Traffic Control during the Operational Evaluation of the Traffic Alert and Collision Avoidance System (TCAS).

**BACKGROUND:** The TCAS Operational Evaluation is being conducted to evaluate the utility of an airborne collision avoidance system. The evaluation will begin in March, 1987 and continue for a two-month period using the TCAS equipment installed in aircraft N857N. This evaluation will be conducted during the regularly scheduled aircraft operations.

**ATC GUIDELINES**

1. ATC will be advised that aircraft N857N is TCAS equipped. This notification will be provided in the remarks section of the flight plan. Although the controllers will be aware that the aircraft is TCAS equipped, they have been instructed not to afford the aircraft any special handling.
2. Individual controllers may request that the use of TCAS be suspended at any time for a period not to exceed five minutes.
3. Extended suspension of TCAS use may be requested by ATC under the following conditions:
  - a. A pilot response to a TCAS advisory requires a deviation from an ATC clearance, which results in an operational error or a suspected operational error.
  - b. Controller detects any unsatisfactory condition related to the use of TCAS.

The suspension of TCAS use for an extended period of time by ATC requires the approval of the facility's area manager or area supervisors-in-charge.

**PROCEDURES**

- During the initial evaluation period (2-3 weeks), the intruder aircraft must be visually acquired prior to executing an evasive maneuver based solely on TCAS.
- While operating in IMC, operate TCAS in STANDBY
- Above FL330, operate TCAS in STANDBY
- The pilot-in-command and First Officer must have completed TCAS training prior to operating TCAS, otherwise TCAS use is illegal. This training may be completed at the Training Center or at your domicile. Such training may be administered by a Chief Pilot, B-727 Check Airman or a qualified ground school instructor. A record of training will be provided for your signature after training is complete.
- Observers from the FAA and industry will be onboard the aircraft to observe TCAS operation. Such observers will be for the purpose of taking notes and documenting pilot comments concerning TCAS. Your cooperation will be appreciated.

#### ICE AND RAIN PROTECTION

(AFM) Engine TAI must be on when icing conditions exist or are anticipated, except during climb and cruise below minus 40°C SAT (Static Air Temperature).

(AFM) Except for landing, minimum N1 RPM for penetrating/operating in icing conditions inflight: 55% light icing; 70% in moderate to severe, when TAT is below minus 6.5°C.

Except for landing, minimum N1 RPM for operating wing anti-ice is 75% when either one pod engine is inoperative or one wing anti-ice valve has failed closed.

(AFM) Window heat on No. 1 and No. 2 windows for all normal flight operations and must be on these windows a minimum of 10 minutes prior to takeoff.

(AFM) Window heat inop: Max speed 250 KIAS below 10,000 feet.

(AFM) For takeoff in standing water or slush, the following are required: chine tires on nosewheel, deflectors on main gear and operating static port heaters when OAT is 35°F or below.

#### MISCELLANEOUS

Navigation lights: Do not use D.C. (battery position) power in flight.

Inboard landing and runway turnoff light operation is limited to 5 minutes unless airplane is in motion.

Do not operate weather radar during refueling near fuel spills or people. Warm up radar in standby only.

(AFM) The flight engineer's seat may not be more than 30° from full forward during takeoff and landing.

(AFM) This airplane is certificated in the Transport category (FAR 25) to operate in the following types of operation:

VFR  
Night Flight  
Instrument (IFR)  
Automatic Approach to Category II Weather Minimums  
Icing Conditions

(AFM) Flight Maneuvering Load Acceleration Limits:

Flaps Up: +2.5g to -1.0g  
Flaps Down: +2.0g to -0.0g

Minimum Required Flight Crew: Pilot, Co-Pilot and Flight Engineer

#### OMEGA NAVIGATION

When using OMEGA for navigation, at least one VOR receiver must be used as a back-up.

#### TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) (As Installed)

(AFM) While operating in Instrument Meteorological Conditions (IMC), operate TCAS in STBY.

(AFM) While operating above FL 330, operate TCAS in STBY.

TCAS Caution information displayed on the weather radar indicator is for information only and is not to be used as a basis for maneuvering to avoid a threat aircraft.

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TCAS CAUTION PROCEDURE

MEMORY

CRT DISPLAY VISUAL SEARCH FOR TRAFFIC		OBSERVE ACCOMPLISH	C, F/O ALL
ADVISORY	INDICATIONS	PILOT RESPONSE	
CAUTION	"C" tone, voice "TRAFFIC" amber light, display on CRT.	If threat traffic is visually acquired, maintain visual acquisition to insure safe separation.	

TCAS WARNINGS PROCEDURE

MEMORY

VISUALLY CLEAR AIRSPACE VERTICAL RATE (IF NECESSARY) RETURN TO LAST CLEARANCE		ACCOMPLISH ADJUST ACCOMPLISH	C C C
ADVISORY	INDICATIONS	PILOT RESPONSE	
CLIMB	European Siren, Voice "CLIMB", red light, green climb arrow on IVSI, display on CRT.	Smoothly establish a climb rate of 1500 FPM. If climb rate is in excess of 1500 FPM when warning sounds, maintain the greater rate.	
DESCEND	European Siren, Voice "DESCEND", red light, green descend arrow on IVSI, display on CRT.	Smoothly establish a descent rate of 1500 FPM. If descent rate is in excess of 1500 FPM when warning sounds, maintain the greater rate.	
LIMIT VERTICAL RATE	European Siren, Voice "LIMIT VERTICAL RATE", red light, lighted amber IVSI segments, display on CRT.	1) Maintain vertical rate out of lighted segments 2) If vertical rate is out of lighted segments, DO NOT change the vertical rate 3) If vertical rate is in the lighted segments, change the vertical rate so that the vertical rate is out of lighted segments. 4) When this WARNING is received after a "CLIMB" or "DESCEND", stop the climb and descent, maintain the vertical rate out of the illuminated segments and return towards last assigned clearance.	
TCAS INVALID	European Siren, Voice "TCAS INVALID", red light, flashing green climb and descend arrows on IVSI, display on CRT.	With visual acquisition of threat traffic, maneuver visually to assure safe separation. Without visual acquisition, discontinue any previously initiated maneuver based on TCAS IVSI information clear the airspace, and return to and/or maintain last clearance.	
WARNING DISCONTINUED	Climb arrow, DESCEND arrow, and IVSI segment lights extinguished.	Discontinue any vertical maneuver based on TCAS IVSI information and smoothly return to and/or maintain last assigned clearance. Minimize the deviation from last assigned clearance.	

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NOTES TO TCAS WARNINGS PROCEDURE

1. Altitude Crossing Maneuver - An altitude crossing maneuver occurs when two aircraft having an initial vertical separation interchange vertical positions as a result of a TCAS WARNING. As a result of following the TCAS WARNING, the TCAS aircraft and the threat aircraft will pass through the same altitude. An altitude crossing is necessary in some situations to insure that adequate vertical separation is provided.
2. TCAS/GPWS Interaction - If for any reason TCAS issues a DESCEND advisory at the same time as a GPWS alert, the GPWS alert takes precedence.
3. "Limit Vertical Rate" Warnings - TCAS may issue a "LIMIT VERTICAL RATE" warning when no changes are required to the existing vertical speed. These preventive advisories are issued to insure that any changes to the vertical speed does not reduce the projected safe separation of the closest point of approach. Therefore, it is unnecessary to alter the vertical speed when the rate of climb needle is out of the lighted segments. Under no conditions is it necessary to leave an assigned altitude when a LIMIT VERTICAL RATE WARNING is received.
4. Expected Altitude Deviations - A majority of TCAS situations that require a deviation from an ATC clearance are usually resolved with altitude deviations of 500 to 800 feet. To minimize the impact of a TCAS maneuver on the ATC system, it is essential that you periodically cross check the IVSI during a TCAS maneuver so that changes in the WARNINGS can be quickly detected once the deviations from the original clearance can be minimized.
5. TCAS Invalid - This advisory is caused either by a pilot electing not to respond to a TCAS warning because the traffic is in sight, or by the traffic performing a maneuver which changes its predicted flight path after a warning is issued. When you receive this warning, discontinue any TCAS maneuver, clear your airspace and return to your assigned altitude.
6. Caution/Warning Lights and Aural Annunciations - These lights and annunciations may be silenced at your discretion by depressing either the Captain's or First Officer's caution/warning lights.

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## B - 7 2 7 O P E R A T I O N S M A N U A L

## COCKPIT PREPARATION CAPTAIN (AMPLIFIED) Continued

ALTITUDE ALERT SYSTEM .....	CHECK
Altitude Selector - SET MORE THAN 1,000 FT ABOVE FIELD ELEVATION.	
Altitude Selector - PRESS IN AND SLOWLY SET TO FIELD ELEVATION.	
As selected altitude nears 1,000 ft. above field elevation, the tone should sound and the alert light illuminate.	
As the selected altitude nears 400 feet above field elevation, the alert light should extinguish and tone remain silent.	
GPWS .....	TEST
Depress test switch and check for aural signal, PULL-UP and GLIDE SLOPE commands.	
COMPASSES .....	SYNC AND X-CHECK
Observe warning flags retracted. Cross check heading of RMIs with course indicators and standby compass.	
STATIC SOURCE SELECTOR .....	NORMAL
MACH AIRSPEED WARNING .....	TEST
Position test switch to No. 1 and then No. 2 and observe clacker sound in each position.	
COMPARATOR .....	TEST
STANDBY HORIZON .....	SET
Check erect and pitch attitude set.	
YAW DAMPERS .....	ON
Check both guarded switch covers down.	
CENTER INSTRUMENT PANEL .....	CHECK
Compare each set of engine instruments for uniform indication.	
FLIGHT RECORDER .....	CHECK - OFF
Place test switch ON - when light extinguishes return switch to OFF. Light should extinguish when aircraft generator is put on bus.	
RADAR .....	STANDBY
CRT DISPLAY CONTROL .....	LIST
TCAS .....	TCAS/WX, STBY
Observe the green TCAS on light illuminated on the TCAS control panel. Allow a 6-second warm-up period.	
TCAS (First flight of the day) .....	TEST
Select self-test and check for aural signals and indications on IVSI. Observe a V - followed by a logic code and the word PASS in blue on the radar CRT. A failed self test is indicated by the amber TCAS FAIL light on the IVSI, the red TCAS FAIL light on the TCAS control panel and the message FAIL followed by a maintenance code on the radar CRT.	
PASSED TEST .....	AUTO
FAILED TEST .....	OFF
SPEED BRAKE LEVER .....	DOWN DETENT
PARKING BRAKE .....	SET
THRUST LEVERS .....	FREE & CLOSED
START LEVERS .....	CUTOFF

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#### MISCELLANEOUS INSTRUMENTS (Cont'd)

##### Clocks

Three clocks are installed, one on each pilot's panel and one on Flight Engineers panel.

##### Standby Horizon Indicators

One standby horizon indicator will be on the pilot's center panel.

##### Altitude Alerting System

One controller on the center instrument panel, two lights, one on each pilot's panel and an altitude alert speaker on the aft overhead panel comprise the altitude alert system.

##### Mach Airspeed Warning System

The two Mach airspeed warning systems, located on the aft overhead panel, uses information from the pitot-static system.

##### Ground Proximity Warning System

The ground proximity warning system utilizes aural annunciation and warning lights to advise the pilots of dangerous flight path condition. Two sets of lights, one on each pilot's panel and the ground proximity warning module located on the Forward Electronics (Control Stand) panel serve as the indicators and control.

##### TCAS (Traffic Alert and Collision Avoidance System)

The Traffic Alert and Collision Avoidance System (TCAS) utilizes aural annunciation and warning lights to advise the pilots of both threatening traffic as well as potentially threatening traffic. Two caution/warning lights, a modified IVSI and a modified weather radar indicator serve as the system's indicator. A TCAS control panel is located on the forward electronics (control stand) panel.

##### Pitot-Static System

The pitot-static system provides RAM and static pressure inputs for pressure sensing instruments, Mach/airspeed, altitude and vertical speed indicators, Mach/airspeed warning system and systems which have functions that vary with altitude and airspeed. Three systems are referred to as Captains, First Officers and auxiliary.

All pitot probes and static ports are equipped with heaters for anti-ice protection.

##### Air Data System

The air data system provides altitude and airspeed outputs from pitot-static system pressure inputs. One air data computer is installed. The air data computer is connected to the Captain's pitot-static system. The computer consists of individual modular computers for altitude and airspeed functions. The computer is energized and operates whenever power is on the airplane.

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## WARNING SYSTEMS (Cont'd)

SYSTEM	CONDITION	WARNING	CHAPTER
POWER PLANT	ENGINE FAILURE WARNING	AMBER LIGHT	5-5
	THRUST REVERSER OPERATING	AMBER LIGHT	5-5
	ENG LOW OIL PRESS OR FILTER BYPASS	AMBER LIGHT	5-5
	ENG 2 DUCT ACCFSS DOOR FAULT	AMBER LIGHT	5-5
	ENG FUEL ICING	AMBER LIGHT	5-5
TCAS	TCAS CAUTION - POTENTIALLY THREATENING TRAFFIC	AMBER LIGHT WITH TONE AND SPOKEN WORD "TRAFFIC"	5-14
	TCAS WARNING - THREATENING TRAFFIC	RED LIGHT WITH EUROPEAN SIREN AND SPOKEN PHRASE "CLIMB, DESCEND, LIMIT VERTICAL RATE, TCAS INVALID"	5-14

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**TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS)**

**BACKGROUND INFORMATION:** Aircraft N857N is equipped with a collision avoidance system (TCAS). This system will be operated for an eight month evaluation period in accordance with the procedures specified in this manual. This system only detects aircraft that are transponder equipped. Continued traffic vigilance is still necessary even with TCAS installed.

System Description

The Traffic Alert and Collision Avoidance System (TCAS) is a completely airborne system that interrogates transponders in nearby aircraft once each second. From these interrogations TCAS determines closure rate and predicts altitude separation of the closest point of approach (CPA). If TCAS computes that aircraft separation at CPA warrants notification of the crew, a TCAS Caution will be issued.

A TCAS CAUTION displays information on the weather radar cathode ray tube (CRT) to aid in visual acquisition of conflicting traffic.

If the conflicting traffic continues to close and TCAS determines the aircraft separation of CPA may cause the threat of a near-miss or possible collision situation, the system provides a TCAS WARNING.

A TCAS CAUTION is issued a minimum of 40 seconds prior to CPA.

A TCAS WARNING provides the flight crew with vertical guidance and is displayed on the IVSIs. If separation is adequate, this vertical guidance will prevent the crew from initiating a climb or descent into the traffic. If separation is not sufficient, the warning will be guidance to alter the existing vertical flight path.

A TCAS WARNING is issued a minimum of 25 seconds prior to CPA.

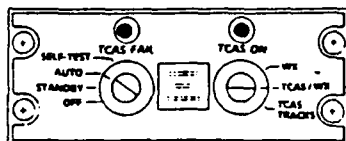
TCAS Control and Display System

The TCAS system provides a visual display of intruder aircraft, and both visual and audible warnings to the flight crew. The TCAS flight deck avionics display and control is divided into five subsystems:

1. TCAS control panel
2. Modified color weather radar CRT
3. Modified IVSIs (C and F/O)
4. TCAS CAUTION/WARNING Lights (C and F/O)
5. TCAS audible warning system

TCAS CONTROL PANEL

This panel is located just aft of the radar controls on the center console.



The function of each switch position is as follows:

- OFF - TCAS components are not powered.
- STANDBY - TCAS is powered but display of information is inhibited.
- AUTO - Normal operation position.
- SELF TEST - Initiates the internal self-test procedure of TCAS components.
- WX - Weather display only, TCAS displays are inhibited.
- TCAS/WX - Provides automatic display switching between weather and TCAS.
- TCAS/TRACKS - Provides a 15-second display of all aircraft equipped with altitude-reporting transponders within 4 miles and  $\pm 1,200$  feet. Below 15,500 feet MSL, all aircraft within 4 miles equipped with non-altitude-reporting transponders also are displayed.

The two lights on the control panel indicate the operating status of the TCAS: the green light shows that power is applied to the system; the red light indicates a system failure.

RADAR CRT DISPLAY

The weather is modified to display TCAS information for interrogated transponder equipped aircraft. Aircraft position data for both TCAS CAUTION and TCAS WARNING situations are displayed on the radar CRT as follows:

Own Aircraft - Represented by a blue chevron below center on the screen and pointed up.

Range Ring - The own aircraft symbol is encircled by 12 asterisks, at clock position 1 through 12. These asterisks are 2 nautical miles from own aircraft position and can be used to estimate range of conflicting traffic.

Intruder Aircraft - Presented by color coded triangles. Intruders whose range exceeds that of the radar CRT, are displayed as a square at the edge of the CRT at the measured bearing. Color coding of displayed information is as follows:

Amber - TCAS CAUTION information. This traffic represents possible threat. Visual search should be accomplished to locate this traffic.

Red - TCAS WARNING information. This traffic represents an actual threat. An IVSI displayed warning will be present for aircraft displayed in red.

Blue - used to represent any non-conflicting transponder equipped traffic within 4 miles, and  $\pm 1,200$  feet.

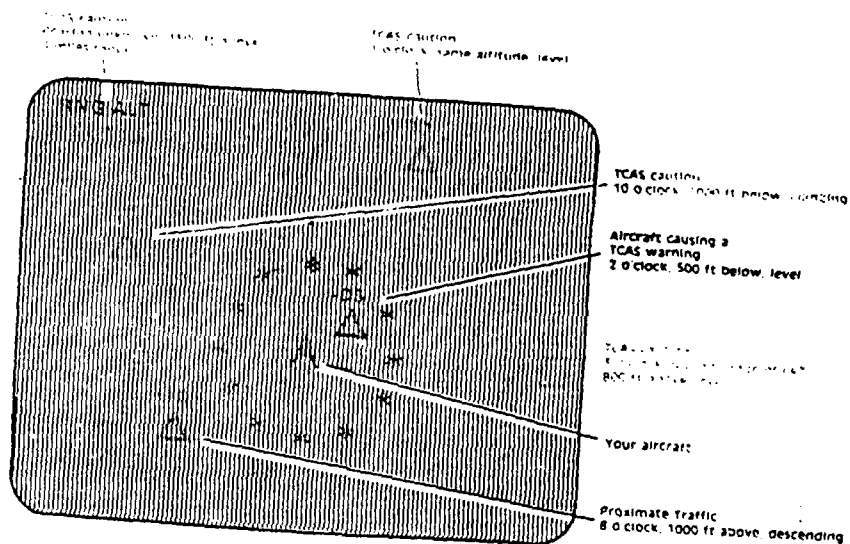
NOTE: Occasionally TCAS may not receive bearing information on an intruder for a short period of time. These aircraft will be displayed in a table in the upper left corner of the radar CRT.

Intruder Relative Altitude - This information is displayed as a signed two digit number in hundreds of feet relative to own aircraft, plus for aircraft above and minus for aircraft below.

+05 (500 feet above)

Whenever the intruder is detected to be changing altitude at a rate of at least 500 FPM, an arrow will appear to the right of the altitude information to indicate a climb or descent.

NOTE: Non-altitude reporting aircraft are displayed with two question marks (??) over the intruder symbol.



WEATHER RADAR DISPLAY

Supplied by Jeppesen Sanderson

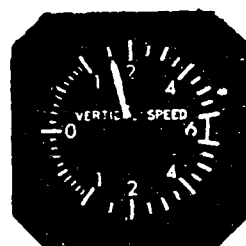


THE DISPLAYS ON THE IVSI:

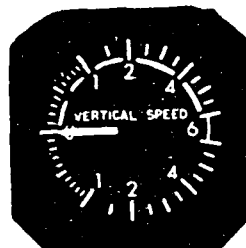
(Refer to the following illustrations)

TCAS warnings are intended to assist you in escaping from a potential collision situation. They are shown on the IVSIs. Both IVSIs on N857N have been replaced with special instruments that appear to be identical to those you have been using. However, two arrows have been added, one above and one below the shaft of the IVSI needle, to give CLIMB or DESCEND advisories, and two sets of "eyebrow" lights have been added just inside the indice marks on the rate scale. These eyebrows, are lighted to give you advisories to not climb, not descend or limit your vertical rate to 500, 1,000 or 2,000 feet per minute.

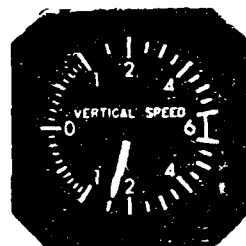
There is an amber FAIL light, located adjacent to the 0,000 feet-per-minute mark; this will light should the TCAS fail.



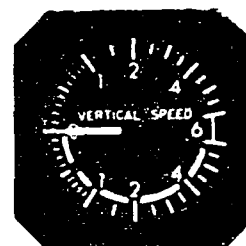
Climb



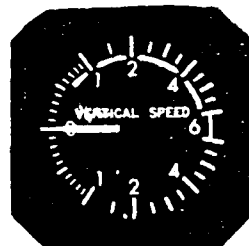
Don't climb



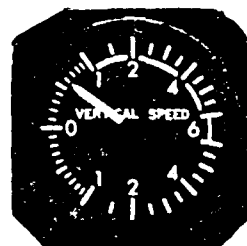
Descend



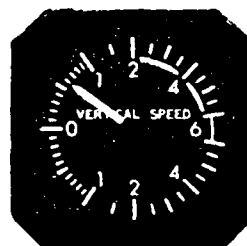
Don't descend



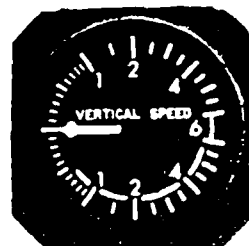
Don't climb faster than 500 fpm



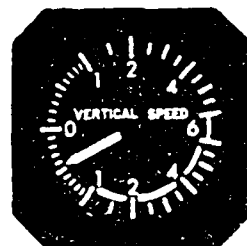
Don't climb faster than 1000 fpm



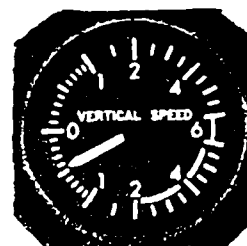
Don't climb faster than 2000 fpm



Don't descend faster than 500 fpm



Don't descend faster than 1000 fpm



Don't descend faster than 2000 fpm

Supplied by Jeppesen Sanderson

CAUTION/WARNING LIGHTS

There are two caution/warning lights mounted on the glare shield (Captain and F/O). Each light has an amber section marked "TCAS CAUTION" and a red section marked "TCAS WARNING." Depressing the light will extinguish the light and silence the aural warning system.

TCAS SPEAKER AND AURAL WARNING

The aural warning system provides selected aural indications (mono-tone or European siren) and voice instructions describing the vertical maneuver displayed on the IVSI. The TCAS speaker is mounted overhead in the cockpit.

OPERATION

Electrical power for the TCAS system is dependent on both the radar selector and the CRT display controls. Two methods may be used to supply power to the TCAS control panel.

1. Place radar selector STANDBY and CRT display control to LIST position.
2. Place radar selector to any Weather function or Map and CRT display control to SCAN position.

NOTE: Power is supplied to the TCAS control panel with radar in STANDBY and CRT display control in SCAN, but range marks will be present on the CRT until a TCAS display is generated.

TCAS DESIGN FEATURES WHICH LIMIT THE TCAS OPERATING ENVELOPE OR DISPLAYS

1. TCAS WARNINGS (IVSI) are not generated for non-altitude reporting aircraft.
2. TCAS does not detect non-transponder equipped aircraft.
3. TCAS Warnings are inhibited below 500 feet AGL.
4. All TCAS displays are inhibited below 1,000 feet AGL when the landing gear is down and locked and the flaps are greater than 25 degrees.

NOTES:

A. When the displays are inhibited, TCAS continues to interrogate and track other transponder equipped aircraft in the vicinity. Therefore, if changes in terrain or aircraft vertical rate result in the aircraft exceeding an altitude of 500 feet AGL (clean configuration) or 1,000 feet (landing configuration), TCAS display information will reappear on the IVSI or the weather radar display. Any intruder aircraft detected while the displays are inhibited will result in TCAS issuing the appropriate aural and visual advisories once the aircraft exceeds the altitude threshold.

B. When responding to a DESCEND advisory while in the landing configuration at low altitude, caution should be exercised as ALL TCAS information is inhibited below an altitude of 1,000 feet AGL. As with all TCAS advisories, visual acquisition should be attempted and all crews should remain altitude aware.

5. DESCEND advisories (IVSI) are inhibited below 700 feet AGL.
6. CLIMB advisories (IVSI) are inhibited whenever the landing gear is down and locked and the flaps are greater than 25 degrees.
7. TCAS receives radar altitude above ground level information from the radar altimeter. If the radar altimeter is inoperative, TCAS will indicate a failure message and the TCAS should be turned OFF.

Supplied by Jeppesen Sanderson

A.2 TCAS TRAINING VIDEO SCRIPT

The Federal Aviation Administration has sponsored the development of the Traffic Alert and Collision Avoidance System (TCAS) which is designed to reduce the potential for midair and near midair collisions. The videotape you are about to see is an integral part of the overall training program for pilots that will be involved in flying Piedmont's TCAS equipped aircraft during the system's operational evaluation period.

TCAS is designed to detect potential collision threats and provide pilots with the information necessary to perform vertical maneuvers to safely avoid those threats.

TCAS interrogates transponders of nearby aircraft to determine range, bearing and altitude.

Results of this interrogation are used to predict the other aircraft's flight path.

TCAS computer determines which tracks will be threats and must be avoided. It then determines the maneuver which will give the safest separation.

The appropriate displays are then turned on to warn the flight crew of the threat.

As long as TCAS is on, it will continue to track transponder equipped aircraft.

TCAS is made up of the following components located in the cockpit:

- TCAS Control Panel
- Weather Radar CRT
- Modified IVSI
- Caution/Warning Lights and Speaker

Control of the system is exercised through the TCAS control panel which is mounted in the lower left corner of the forward display pedestal.

There are two indicator lights and two control switches located on the face of the control panel. The green, TCAS ON, indicator light signifies power is applied to the system and it is operating properly. The red, TCAS FAIL light indicates a system failure.

The left switch controls the operation of the system through its four positions:

In the OFF position the TCAS components are not powered.

Standby supplies system power but inhibits the display of information.

The Self-Test position is spring loaded and is used to initiate the system's built-in-test function.

The right switch controls the connection of TCAS to the system displays through its three positions:

In the weather position, all TCAS displays are inhibited.

TCAS/Weather will provide automatic switching from weather information to TCAS information as threats are detected. No weather information is displayed during a TCAS advisory.

The TCAS/TRACKS position is spring loaded and will provide a 15 second display of all nearby transponder equipped aircraft. At altitudes above 15,500 feet MSL, the system will not display non-MODE-C transponder equipped aircraft. This position may be selected at any time during flight to assist you in locating nearby transponder-equipped traffic. This information is not to be used to perform a maneuver or to deviate from your current flight path.

System Information is displayed on modified cockpit instruments. The relative position of the threat aircraft is displayed on the weather radar CRT. Vertical maneuvering information is displayed on the modified IVSIs.

The weather radar CRT is used to display traffic and its relationship to your aircraft in order to assist you in visually acquiring the traffic. Evasive maneuvers are NOT to be made based on the CRT intruder information.

Your aircraft will be displayed as the blue chevron. A two mile range circle is provided around your aircraft to assist in visually acquiring the traffic and is represented by 12 blue asterisks, located at the 1 through 12 o'clock positions.

Threat information is displayed using combinations of two symbols and three colors.

Aircraft that are outside of display range are shown as squares. Those within CRT display range are depicted as triangles.

The status of any potential threat is indicated by its color. Blue colored symbols represent minimal threat, amber symbols are potential threats that are causing a CAUTION and red symbols are are threats that are causing a WARNING.

In addition to color and symbol coding, each threat aircraft will be accompanied by a data block consisting of two to four symbols.

A plus or minus sign indicates whether the traffic is above or below you.

A two-digit number indicates altitude separation in hundreds of feet between the traffic and your aircraft.

An up or down arrow indicates that the traffic is climbing or descending. If the traffic is level or changing altitude at a low vertical rate, no arrow will be displayed.

If the potential threat is not MODE-C equipped and you are below 15,500 feet MSL, then two question marks will appear in the data block.

Very rarely, TCAS may not be able to track the bearing of some traffic. This is usually caused by a part of your airplane-wing, tail or fuselage-temporarily shielding the TCAS antenna on top of your airplane. Because TCAS uses vertical maneuvers to resolve potential conflicts, the TCAS warning function of the system is unaffected by this circumstance, but the CRT will only show range and relative altitude of this particular aircraft. This information will be shown in the upper left corner of the screen, color-coded in the normal manner to show its status: amber for traffic potential threat causing a TCAS CAUTION and red for traffic causing a TCAS warning. As soon as the system regains bearing information, this traffic will be shown in the normal manner.

Vertical maneuvering information will be displayed on the two modified IVSI's.

Two green arrows have been added, one to indicate climb and one to indicate descent. In addition, two sets of amber segment lights have been added to warn you to not climb, not descend or limit climb or descent to 500, 1000 or 2000 feet per minute. In addition, there is an amber fail light which will illuminate should there be a TCAS failure.

Under certain conditions, the system may issue a TCAS invalid advisory. This will be represented on the IVSI by the alternate flashing of the green climb and descend arrows.

In addition to the warning symbols displayed on the CRT, a set of glare shield warning lights and a voice annunciator will alert the flight crew to potential threats.

When traffic is classified as a potential threat, the amber section of the Caution/Warning light is illuminated. This is accompanied by a 3 second tone followed by the word TRAFFIC. Should a potential threat become an actual conflict, the red WARNING light is lit and the annunciator system sounds a European siren for 2 seconds, followed by a verbal warning. The IVSI's will then be illuminated to show you if it is necessary to change your vertical rate.

The Caution/Warning lights and the audio warning can be silenced by depressing either Caution/Warning light. If not cancelled, both lights and aural warning will remain on until the conflict has been resolved. The CRT and the IVSI will display the TCAS information until the conflict is resolved, regardless of whether or not audio is silenced.

On the first-light-of-the-day, TCAS is turned on and initialized. To do this, turn the power control knob to "AUTO", the display control knob to TCAS/Weather, the weather radar Mode Selector to Standby and the weather radar CRT to LIST. Wait 6 seconds for TCAS to warm up, then turn power control knob to "SELF-TEST" and release. TCAS will now perform its self test functions.

You will see each IVSI display and hear each TCAS warning message.

At the end of the test, the weather radar will show the TCAS screen and the PASS message. TCAS is now ready for flight.

If a FAIL message appears, note the FAIL CODE in the aircraft log and TURN TCAS OFF.

When a TCAS caution is issued, in addition to the amber caution light and aural warning you will see the intruder displayed on your weather radar display as an amber target. Use this CRT information to determine the intruder's bearing range and relative altitude and begin your visual search for the traffic. If you see the traffic, use your own judgment to avoid it. DO NOT MANEUVER based solely on TCAS CAUTION displayed information. In most cases the traffic will not become a threat and will not result in a TCAS warning.

When you receive a CLIMB warning, clear airspace and make a normal transition to a 1,500 foot per minute rate of climb. If you are already climbing faster than that, continue at your present rate. The IVSI display will change as the threat lessens. If the IVSI changes to a Limit Vertical Rate, stop your climb and level off. When the IVSI lights go out, begin your descent back to your clearance altitude.

When you receive a DESCEND warning, again, clear airspace, and make a normal transition to a 1,500 foot per minute rate of descent. If you are already descending faster than that, continue at your present rate. The IVSI display will change as the threat lessens. If the IVSI changes to a Limit Vertical Rate, stop your descent and level off. When the IVSI lights go out, begin your climb back to your clearance altitude.

A vertical rate of 1,500 feet per minute should be your target rate when responding to a climb or descend warning. Your response is not intended to be a precision maneuver, and reasonable deviations greater than the target rate are allowed.

When you receive only a LIMIT VERTICAL RATE warning, you may not have to do anything. If you are on an ATC assigned altitude, do not leave that altitude. If the needle is not in the yellow segments, do not maneuver. But, IF the IVSI needle IS in the yellow segments, smoothly change your rate of climb - or descent - to bring the needle out of the yellow segments.

Very rarely a warning might change to a TCAS INVALID. The TCAS INVALID advisory can be caused either by a pilot electing not to respond to a TCAS WARNING because the traffic is in sight or by the traffic performing a vertical maneuver which changes its predicted flight path after a TCAS WARNING is displayed. When you receive this warning, clear your airspace and return to your previous clearance.

An altitude crossing maneuver occurs when a TCAS Warning causes you to climb or descend through the intruder's altitude. If the intruder's altitude is changing, an altitude crossing may be necessary to provide adequate separation.

If you receive a TCAS descend warning and a Ground Proximity warning at the same time, follow the ground proximity warning.

TCAS does have some limitations. TCAS cannot see aircraft which do not have a transponder.

If an aircraft has a non-MODE-C transponder, TCAS will be able to track it, and issue a caution, but will not be able to issue a warning.

When your aircraft is on the ground or just after take-off or in the final stages of approach, all TCAS displays are inhibited. - When flying above flight level 330, turn TCAS to STANDBY.

For the purpose of the flight evaluation, TCAS will be used in visual conditions only. When in instrument conditions, put TCAS in standby.



In any TCAS maneuver, it is important to remember the following:

Visually search for the intruder.

The weather radar CRT is to help you locate traffic.

Clear the airspace before performing the TCAS maneuver.

The IVSI is your primary instrument.

If you receive a CLIMB or DESCEND Warning, establish a 1500 fpm rate. If already climbing or descending, maintain the greater rate.

Minimize the deviation from your clearance during the maneuver and return to your clearance as soon as the IVSI lights go out.

Notify ATC of any deviations in altitude.

Information presented in this film can be found in more detail in your operations manual.

If at any time during this evaluation you experience problems with TCAS, notify the test conductor or observer.

ENCOUNTER GROUP 1

SCENARIO 1

Your aircraft is in level cruise on an assigned altitude.

SCENARIO 2

Your aircraft is in level cruise on an assigned altitude.

SCENARIO 3

Your aircraft is descending at 2,000 fpm.

SCENARIO 4

Your aircraft is in level flight on an assigned altitude.

ENCOUNTER GROUP 2

SCENARIO 1

Your aircraft is in level cruise on an assigned altitude.

SCENARIO 2

Your aircraft is climbing at 2,000 fpm.

SCENARIO 3

Your aircraft is in level cruise on an assigned altitude.

ENCOUNTER GROUP 3

SCENARIO 1

Your aircraft is in level cruise on an assigned altitude.

SCENARIO 2

Your aircraft is in level cruise on an assigned altitude.

SCENARIO 3

Your aircraft is descending at 2,000 fpm.

### A.3 TRAINING SYLLABUS AND QUIZ

TCAS Training Lesson Plan. The following guidelines are provided to ensure that the TCAS training program is consistently implemented at all locations. These guidelines describe the topics that should be covered during the training and the major points of emphasis. The TCAS training program will consist of a 90 minute block of time during which the following will be presented.

- a. INTRODUCTION - A brief discussion of the purpose of the TCAS evaluation. Also a review of the fact that observers will be on board to monitor the crew's use of TCAS and record data on TCAS events. Finally, a review of the fact that the FAA will not violate a pilot for leaving an assigned altitude while responding to a TCAS warning.
- b. VIDEO TAPE - The tape was developed to cover the operational aspects of TCAS. The instructor may stop the tape at any time to place additional emphasis on an item in the tape. Any questions resulting from watching the tape will be answered before proceeding to the next item. The video tape should be stopped at the beginning of the TCAS Encounter Group 1.
- c. OPERATIONS MANUAL SUPPLEMENT - A discussion of the TCAS operations manual supplement and operations manual bulletin will emphasize the following items:
  1. OMB ATC guidelines, procedures, pilot immunity. (pg. OMB 86-1)
  2. AFM Limitations. (pg. 1-12)
  3. DO NOT MANEUVER on TCAS CAUTION information alone. (pg. 1-12)
  4. Responses should feel similar to the start of en route climbs or descents. (pg. 3-52A)
  5. Memory items from procedures section. (pg. 3-52A)
  6. Responses to a "CLIMB" or "DESCEND" advisory - Use 1,500 feet per minute. (pg. 3-52A)
  7. Response when a TCAS WARNING is downgraded or discontinued. Return towards original clearance, keep IVSI needle out of the lighted segments, and minimize deviation from last assigned clearance. (pg. 3-52A)
  8. Minimize magnitude of deviation from last assigned clearance while responding to a TCAS WARNING. (pg. 3-52A)
  9. Response to a TCAS invalid. (pg. 3-52A)
  10. Altitude crossing and TCAS/GPWS Interaction. (pg. 3-52B)
  11. TCAS design Features which limit the TCAS Operating Envelope or Displays. (pg. 5-14-29)
  12. Normal equipment operating configuration. (pg. 3-20)

Weather Radar:       STANDBY and LIST or ON and any position

TCAS:                 AUTO and TCAS/WX

- d. TCAS TEST and Certification - A test on Group II of the scenarios will be administered after the training is complete. Less than a 100% score on Group II will require additional training in deficient areas and a test on Group III scenarios. Less than a 100% score on Group III will disqualify the candidate from the TCAS Evaluation Program.
- e. Questions - The instructor will answer any questions raised by the pilot.

TCAS TRAINING CERTIFICATE

CAPT \_\_\_\_\_ PAY \_\_\_\_\_  
F/O \_\_\_\_\_ NO. \_\_\_\_\_ BASE \_\_\_\_\_ DATE \_\_\_\_\_

TEST QUESTIONS

ENCOUNTER SET 2. SCENARIO 1.

Your aircraft is in level cruise on an assigned altitude.

@ CAUTION 1. Look for the intruder to be:

- a. Dead ahead and level
- b. 12 o'clock, above, and level
- ☒ c. 12 o'clock, above, and descending
- d. 12 o'clock, below, and level

@ WARNING 2. Your maneuver is to:

- ☒ a. Clear airspace and climb at 1500 fpm
- b. Clear airspace and descend at 1500 fpm
- c. Remain level

@ LIMIT 3. At this command you should:

VERTICAL  
RATE WARNING

- a. Clear airspace and descend
- ☒ b. Clear airspace and level off
- c. Continued climbing

@ IVSI LIGHTS 4. When IVSI lights go off you should:  
OFF

- a. Request a new clearance from ATC
- ☒ b. Notify ATC that you are returning to your altitude
- c. Remain level

ENCOUNTER SET 2. SCENARIO 2.

Your aircraft is climbing at 2000 fpm.

- @ CAUTION 1. Your maneuver should be to :
- a. Continue your climb but look up and ahead for traffic.
  - b. Turn right to avoid intruder.
  - c. Establish a 1500 fpm descent.
- @ WARNING 2. Your maneuver should be to:
- a. Turn right to avoid intruder.
  - b. Establish a 1500 fpm descent.
  - c. Keep IVSI needle out of yellow by reducing climb.

ENCOUNTER SET 2. SCENARIO 3.

Your aircraft is in level cruise on an assigned altitude.

- @ CAUTION 1. At the "TRAFFIC" caution you should:
- a. Maneuver to avoid traffic based on WX CRT display.
  - b. Look ahead and below for traffic.
  - c. Request a new altitude clearance from ATC.
- @ WARNING 2. At the "CLIMB" warning you should:
- a. React quickly with a large climb rate.
  - b. React smoothly with a 1500 fpm climb rate.
  - c. Request a climb rate from ATC.
- @ LVR WARNING 3. At the "LIMIT VERTICAL RATE" warning, you should:
- a. Continue you climb.
  - b. Clear airspace and level off.
  - c. Clear airspace and descend.
4. When the IVSI lights go out it means:
- a. TCAS can no longer resolve the conflict.
  - b. It is safe to return to your assigned altitude.
  - c. TCAS has failed.

## APPENDIX B

### OBSERVER TRAINING PROGRAM MATERIAL AND INSTRUCTIONS TO OBSERVERS

Cockpit test observers with extensive aeronautical or TCAS experience collected data on the operational effectiveness of TCAS. Observers were provided from the Air Line Pilots Association (ALPA), Air Transport Association of America (ATA), Federal Aviation Administration (FAA), MITRE, National Transportation Safety Board (NTSB), and ARINC Research Corporation. The test observers recorded objective data on the flight conditions at the time of each TCAS advisory and made subjective assessments of the utility of the displayed TCAS Cautions and Warnings. They were asked to record location, flight conditions, aircraft configuration, ATC situation, and flight crew activities at the time of each TCAS alert. The observers made subjective evaluations of the utility of the displayed Cautions and Warnings in the context of the planned actions of the flight crew, ATC clearance, and communications between the controllers and aircraft during the encounter. The observers were also tasked with the responsibility for obtaining flight crew comments on the system's displays and procedures.

In order to carry out their intended function, test observers had to be familiar with air carrier flight deck procedures, Air Traffic Control procedures, TCAS concepts, and operation of the Dalmo Victor avionics and recorder system.

Observer training sessions took place prior to the start of the evaluation program and as necessary during the evaluation. This training included briefings on the TCAS concept of operation, description of the operation of the Dalmo Victor equipment, explanation of the data collection forms and voice recorder operation, presentation of the flight crew training program, and orientation on administrative procedures.

Each observer was issued appropriate flight deck authorization by Piedmont and the FAA's Carolina Flight Standards District Office.

## B.1 TCAS OBSERVER TRAINING



## **TCAS OBSERVER TRAINING LESSON PLAN OVERVIEW**

### **1 PILOT TRAINING**

- \* FILM**
- \* OPERATIONS MANUAL**
- \* QUIZ**

### **2 OBSERVER TRAINING**

- \* POINTS TO OBSERVE**
- \* EVALUATION FORMS**
- \* OBSERVER NOTEBOOK**

### **3 COCKPIT OPERATIONS TRAINING**

- \* DISPATCH / LISTING**
- \* COCKPIT CHECKIN**
- \* IN-FLIGHT CONSTRAINTS**

## POINTS TO OBSERVE

### 1 FLIGHT NUMBER DATA

- \* FLIGHT NUMBER
- \* LEG / DEPARTURE / DESTINATION
- \* DATE AND TIME

### 2 ADVISORY DATA

- \* TIME OF CAUTION OR WARNING
- \* FLIGHT PATH GEOMETRY
- \* CREW REACTION TO ADVISORIES

### 3 FLIGHT PATH DATA

- \* PHASE OF FLIGHT
- \* ALTITUDE AND HEADING
- \* CONFIGURATION
- \* METEOROLOGICAL CONDITIONS

### 4 CREW DATA

- \* EXPERIENCE WITH TCAS
- \* UNDERSTANDING OF DISPLAYS AND COMMANDS
- \* USEFULNESS OF ADVISORY

## **OBSERVER KIT**

### **1 NOTEBOOK**

- \* INSTRUCTIONS TO OBSERVERS**
- \* EVALUATION FORMS**
- \* OPERATIONS MANUAL**
- \* FAILURE REPORTING PROCEDURES**
- \* OPERATION OF TAPE RECORDER**
- \* DATA RECORDER AND CLOCK INSTRUCTIONS**
- \* PHONE NUMBER LIST**

### **2 EN ROUTE CHARTS**

### **3 STAMPED, ADDRESSED ENVELOPES**

### **4 TAPE RECORDER AND CASSETTE TAPES**

### **5 SUPPLEMENTAL TCAS TRAINING MATERIAL**

### **6 PIEDMONT AIRLINES FLIGHT SCHEDULE**

### **7 NOTEPAD AND PENCILS**

## **JUMPSEAT PROCEDURES**

### **1 LISTING AS A JUMPSEAT RIDER**

- \* NOTIFY DISPATCH IN ADVANCE**
- \* IDENTIFY SELF AND PURPOSE OF TRIP**

### **2 BOARDING THE AIRCRAFT**

- \* CHECK IN WITH OPERATIONS IN ADVANCE OF BOARDING**
- \* PRESENT CREDENTIALS TO CAPTAIN UPON BOARDING**
- \* INFORM FLIGHT CREW OF PURPOSE OF OBSERVATION**

### **3 WHILE IN FLIGHT**

- \* OBSERVE "STERILE COCKPIT" REGULATIONS BELOW 10000 FEET**
- \* DO NOT ADVISE CREW MEMBERS DURING A TCAS ENCOUNTER**
- \* YOU ARE A GUEST IN THE COCKPIT**

## OBSERVER CHECKLIST

### 1 BEFORE FLIGHT

- \* VERIFY OPERATIONAL TCAS
- \* VERIFY OBSERVER'S NOTEBOOK
- \* VERIFY OPERATING HEADSET

### 2 AT TCAS CAUTION

- \* RECORD TIME
- \* RECORD INTRUDER POSITION AND TRACK
- \* RECORD FLIGHT CONDITIONS AND AIRPLANE CONFIGURATION
- \* MAKE NOTE OF PILOT REACTION TO ADVISORY AND VISUAL ACQUISITION
- \* MAKE NOTE OF ATC COMMUNICATIONS

### 3 AT TCAS WARNING

- \* RECORD TIME
- \* MAKE NOTE OF IVSI COMMAND
- \* RECORD INTRUDER POSITION AND TRACK
- \* RECORD FLIGHT CONDITIONS AND AIRPLANE CONFIGURATION
- \* MAKE NOTE OF PILOT REACTION TO ADVISORY VS ELECTIVE MANEUVER
- \* MAKE NOTE OF ATC COMMUNICATIONS

### 4 IN THE EVENT OF A TCAS FAILURE

- \* RECORD FAILURE CODE
- \* NOTIFY ARINC RESEARCH

### 5 AT END OF TRIP

- \* COMPLETE OBSERVER EVALUATION FORMS
- \* MAKE SURE THE PILOT RESPONSE FORMS ARE COMPLETED
- \* MAKE SURE THE OBSERVER NOTEBOOK IS READY FOR THE NEXT OBSERVER
- \* MAIL COMPLETED FORMS TO ARINC

B.2 INSTRUCTIONS TO OBSERVERS

## OBSERVER PROCEDURES

### INTRODUCTION

The flight observer performs the most important role in the evaluation of TCAS. He is the man on the spot who uses his aeronautical training and experience to evaluate the potential impact of TCAS on the operation of the aircraft and on the ATC system. The flight observer is expected to mentally project himself into the role of pilot flying the aircraft.

The flight observer must not in any way interfere with the flight crew and the performance of their duties. The flight observer is a guest of the flight deck and must not interject his opinions or comments into the flight crew's actions, regardless of the observer's aeronautical ratings, experience, or position.

### Scheduling

ARINC Research will schedule each observer individually. The detailed procedures will be coordinated with each observer by telephone and written correspondence.

### Access to the Flight Deck

Each observer will be provided with a letter from the FAA which will serve as written authority for admission to the flight deck of Piedmont Airlines flights. The purpose of this authorization is to observe in-flight operations and record data.

The observer needs to check in at Piedmont Flight Operations prior to the flight. Finding and gaining entrance may be a problem at an unfamiliar airport, so allow sufficient time (45 minutes before scheduled departure.) Any gate agent should be able to direct you to Flight Operations.

Once at Flight Operations state the nature of your business and you will be given a Jump Seat Boarding Pass to fill out. On the following page is an example of a pass and how it should be filled out.



# ACM / JS BOARDING PASS

① ☐ ACM  
☒ JS

DATE OF ISSUE  
 ② 3/6/84

FROM ③ BWI	TO ④ GSO	FLIGHT ⑤	DATE ⑥ 3/7/84
NAME ⑦ MR. I. OBSERVER		⑧	STATION ⑨
INT DD ⑧		⑩ ARINC	⑪ J. Observer

FILE COPY  
 (FILE WITH 101 FORMS)

## Boarding Pass

There are eleven blocks an observer needs to fill out. Explanations are given for those that are not self explanatory.

2. Date of Flight
3. Point of Departure
4. and 5.

An aircrafts daily route will encompass several different flight numbers. Your pass is only good for the segment covered by a particular flight number. Enter the identifier of the airport where the flight number terminates. You will have to deplane at that time and receive another pass for the next numbered flight sequence.

6. Date of Flight
7. Observer Name
8. INT DD: Always enter these letters. They specify the location of your approval authority (Winston Dispatch).
9. Employee Number or N/A
10. Enter the company you represent
11. Sign
12. Flight Operations will fill in these blocks.



### Observer Kit

Once in the cockpit you will find a blue observer kit. This kit will contain earphones, cassette recorder and cassettes, mailing envelopes, observer evaluation forms, and associated TCAS information.

### Flight Activity

The observer is to project himself into the pilot's role as if he were flying the aircraft. During the flight the observer must maintain an informal record of the clearances issued by ATC, along with the times they are issued. He should maintain a record of flight progress with a notation of the time the flight crosses VORs, departs an altitude, arrives at an assigned altitude, enters holding, departs holding, and any other significant events that occur during the flight.

The observer should explain to the Captain that he will be following the flight activity in various ways. An observer might want to use the tape recorder or simply use paper and pen. In any case the observer should carefully point out that these records are being made only for collection of TCAS performance data and will not be used for any other purpose.

The Flight Engineer might be helpful in detailing the expected routing and activity, but be careful not to interfere with crew activities. DO NOT ASK QUESTIONS IN FLIGHT BELOW 10,000 FEET.

The overall theme of the observer program is to produce an independent on-scene assessment of TCAS system performance, identify problem areas, evaluate flight crew integration with TCAS, and develop constructive recommendations for change to enhance safety and production development.

### Observer Recording

After observing a flight, TCAS evaluation forms should be completed. These forms contain detailed instructions for completion and are an attempt to gather analytical and subjective information on all facets of TCAS performance.

The observer evaluation forms may not cover an item of information which is significant. A survey of this type can never completely portray a complex event. The survey may also fall short in presenting the observer the opportunity to air his subjective opinions of the conflict scenario just witnessed.

Any time a significant event (conflict CAUTION or WARNING) occurs, record a summary of the incident. As a suggestion the narrative may include comments on the areas listed below or an expansion of areas addressed in the evaluation forms.

1. Date/Flight Number
2. Where/When
3. Aircraft (857) Intentions or Planned Route
4. First Indication
5. Sequence of Events
6. Timeliness of TCAS Information
7. Correctness
8. Usefulness
9. Conflict Resolution
10. Comments

#### Post Flight/Observation Period

An evaluation form should have been completed for each TCAS WARNING received. If none were received then every time a crew changed over a critique of the system should have been conducted with the pilots before they departed. The data collection process will only work if the observer takes it upon himself to ensure that both pilot and observer forms are completed. At the completion of your observer duty, collect all forms (Pilot and Observer) and any cassette narrative you have made. Check to see if any forms have been completed by pilots when no observer was aboard. They would be in the large envelope in the observer kit. Place all material in an appropriate envelope and mail to ARINC Research. Self-addressed stamped envelopes are contained in the observer kit.

Should any difficulty be encountered, inform ARINC Research (301)266-4712 or toll free 1-800-638-4908 extension 4712.

#### Malfunction

Although the system has continuous self-monitoring features, you may wish to check the system to assure yourself that it is operational. Normally, you will check the system once prior to your first flight of the day.

APPENDIX B.3 OBSERVER BULLETINS

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TCAS OBSERVER BULLETIN

APRIL 2, 1987

\*\*\*\*\*

1. ATC - Pilot Communication:

Please keep track of ATC - pilot communication prior to, during, and following any TCAS encounters, especially WARNINGS. Of specific interest:

- whether the traffic was called out to the pilot by ATC,
- whether the traffic was called in to ATC by the pilot,
- anything that was said by either,
- which sector was controlling the aircraft,
- any unusual communication which you would not expect if the aircraft was not TCAS-equipped.

2. Phone-in of Warning Information:

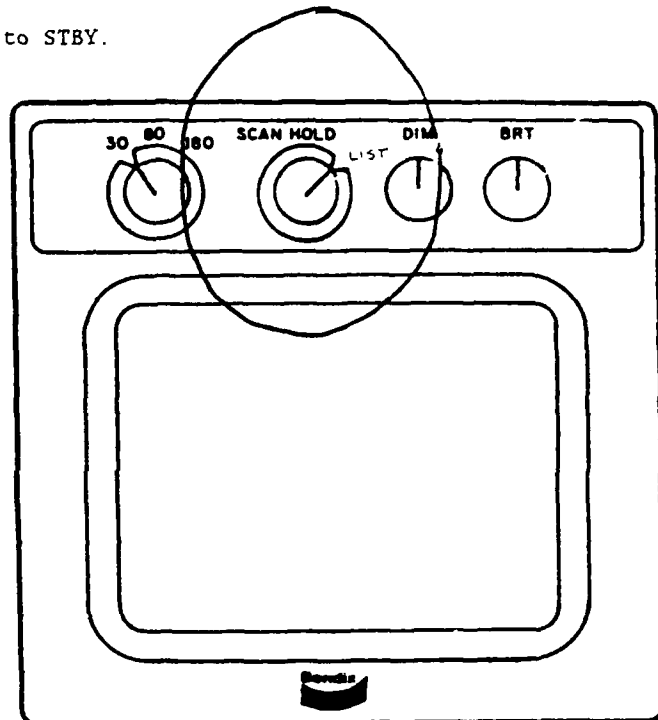
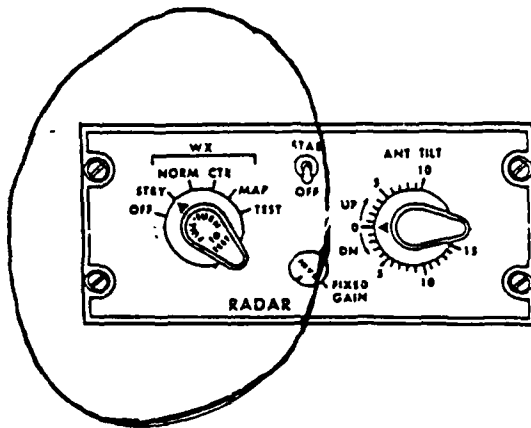
If you observe a warning during one of your legs, as soon as the aircraft arrives at its next scheduled destination, please notify Arinc of the details of the encounter including time, location, and which ATC sector was controlling the aircraft.

\*\*\*\*\*  
TCAS OBSERVER BULLETIN

MAY 28, 1987  
\*\*\*\*\*

PLEASE NOTE THE FOLLOWING PROCEDURES FOR OPERATING THE WEATHER RADAR  
EQUIPMENT FOR USE WITH TCAS:

- 1: Weather Radar control switch set to STBY.
- 2: Weather Radar CRT set to LIST.



\*\*\*\*\*

TCAS OBSERVER BULLETIN #3

JULY 30, 1987

\*\*\*\*\*

A problem has been noted when the TCAS aircraft is operating in the vicinity of Chambers Field, NAS Norfolk. Chambers Field is located approximately 4nm northwest of Norfolk International Airport.

The problem is that numerous non-Mode-C targets are displayed in a very short time. Many of these targets result in the issuance of a TCAS Caution or Traffic Advisory (TA) and these TA's often overlap. On two occasions, as many as six TA's have been issued within a period of less than 10 seconds. During this time period, the TCAS aural alert is on almost continuously and can become somewhat distracting. These TA's are caused by the TCAS aircraft overflying U.S. Navy ships anchored near NAS Norfolk.

Any Navy or Coast Guard vessel longer than 54 feet is equipped with a transponder or IFF. These avionics respond to the Mode-C interrogation pulse transmitted by the TCAS avionics. The pulse repetition rate of the IFF is 4 times faster than the ATCRBS transponder replies which may cause TCAS to think more than one transponder is responding to the interrogation. Although the ships are supposed to turn their IFF's off while in port, it appears that this frequently does not occur.

All observers should be aware that this problem can occur when operating in the Norfolk area. The problem has typically occurred after departing from runway 5 and the turn to a westbound heading is completed. The problem may also be noted when flying over the ships anchored just off the departure end of runway 5. If you observe this problem, please record it on your observer form and answer any questions the crew may have regarding the displayed data.

\*\*\*\*\*

TCAS OBSERVER BULLETIN #4

AUGUST 20, 1987

\*\*\*\*\*

The FAA has removed the requirement to visually acquire an intruder aircraft prior to responding to a TCAS Warning. The crews have been notified via an Operations Manual Bulletin of this removal.

As a result, the only action required prior to following a TCAS Warning is to clear the airspace into which the aircraft will be maneuvered. The crews are authorized to use the procedures contained in Section Three of their Operations Manual. A copy of these procedures is contained in the Observer Notebook.

APPENDIX C

TCAS OBSERVER FORMS



## INSTRUCTIONS

The TCAS Evaluation Form is the primary vehicle through which an observer communicates. This form allows you to comment on TCAS hardware and flight crew response to TCAS information.

Each questionnaire contains sections for recording two CAUTIONS, one WARNING and some end of tour questions. If an event included a TCAS WARNING you must still complete the information on the TCAS CAUTION sheet. The two sheets - TCAS CAUTION/TCAS WARNING - are sequential. Should you need to record more information extra sections are contained in the observer book.

There is also a portable recorder and blank cassettes in the observer kit. Use the tape recorder to supplement the information given in the evaluation forms.

The pilots also have an evaluation form to fill out. Please take it upon yourself to insure that the pilots' evaluation forms are completed.

At the completion of your observer duty, collect all forms (Pilot and Observer) and any cassette narrative you have made. Place them in an appropriate envelope and mail to ARINC Research. Self-addressed stamped envelopes are contained in the observer kit.

\*\*\*\*\*  
WERE THERE ANY ENCOUNTERS THAT TCAS DID NOT PREDICT? Yes \_\_\_\_\_ No \_\_\_\_\_

If so, as soon as possible ask ATC if:

They had the traffic	Yes _____	No _____
Was the aircraft transponder equipped?	Yes _____	No _____
Was there a Mode C reporting altitude?	Yes _____	No _____

Please give a full narrative of the encounter on the back of this questionnaire.

\*\*\*\*\*

OBSERVER QUESTIONNAIRE

OBSERVER \_\_\_\_\_ DATE \_\_\_\_\_

TCAS CAUTIONS

1. Caution Number \_\_\_\_\_ Flight Number \_\_\_\_\_
2. Flight Leg From \_\_\_\_\_ To \_\_\_\_\_
3. Time/Aircraft Position \_\_\_\_\_ / \_\_\_\_\_
4. Phase of Flight: Departure \_\_\_\_\_ Climb \_\_\_\_\_ Approach \_\_\_\_\_  
Descent \_\_\_\_\_ Maneuvering in Terminal Area \_\_\_\_\_
5. Configuration: Flaps \_\_\_\_\_ less/more \_\_\_\_\_ than 15 degrees  
Landing gear \_\_\_\_\_ up/down \_\_\_\_\_
6. Conditions: VMC Day \_\_\_\_\_ Night \_\_\_\_\_ Marginal \_\_\_\_\_  
(vis. in miles) \_\_\_\_\_
7. Identify the sequence of events by circling the appropriate numbers.

ATC Advisory	1st	2nd	3rd	4th	NONE
TCAS Caution	1st	2nd	3rd	4th	NONE
TCAS Warning	1st	2nd	3rd	4th	NONE
Visual Contact	1st	2nd	3rd	4th	NONE
8. Type Intruder \_\_\_\_\_  
Unknown \_\_\_\_\_
9. Understanding the CRT display was  
easy \_\_\_\_\_ adequate \_\_\_\_\_ hard \_\_\_\_\_
10. Was any conflict apparent between TCAS and ATC information?  
Yes (explain) \_\_\_\_\_ No \_\_\_\_\_

TCAS WARNING (fill out TCAS CAUTION Section first)

Observer \_\_\_\_\_ Date \_\_\_\_\_

Followed CAUTION No. \_\_\_\_\_ Flight Number \_\_\_\_\_

1. Aural Command      Yes \_\_\_\_\_ No \_\_\_\_\_
2. Did the crew silence it? Yes \_\_\_\_\_ No \_\_\_\_\_
3. Did the crew appear to understand the IVSI displayed information?  
Yes \_\_\_\_\_ No \_\_\_\_\_
4. Was the maneuver accomplished? Yes \_\_\_\_\_ No \_\_\_\_\_ (if not why?)

Based upon all other information available (i.e., visual, ATC, etc.) did the TCAS WARNING:

- a. Appear proper for resolution of the conflict?
- b. Was the WARNING what you expected?
- c. Was it necessary? (explain)

During the encounter was there complete agreement among the crew as to the meaning of TCAS data and procedures to follow?

If the crew maneuvered in response to TCAS what is your impression of the impact upon the ATC controller?

## OBSERVER

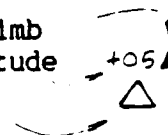
Diagram the encounter situation which caused the WARNING. Ask the crew for help in recording the CRT display. Use the same symbols as those displayed on the CRT. Add letters to the triangles to denote the sequence. See example in observer book.

### Location of Target

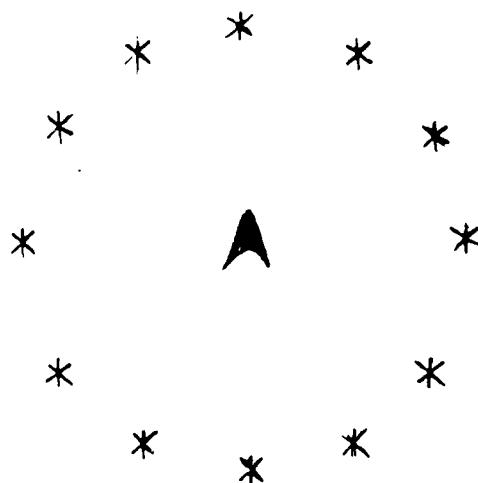
- a. Caution occurred
- b. Warning occurred
- c. Visual Contact
- d. End of Advisory

### Symbols

Descent or Climb  
Relative Altitude  
Basic Symbol



RNG ALT



OBSERVER QUESTIONS - END OF TOUR

1. Did TCAS traffic information appear to facilitate visual acquisition of intruder aircraft? (explain)
  
2. Are crews able to sort multiple target information and:
  - a. Properly prioritize targets? Yes \_\_\_\_\_ No \_\_\_\_\_
  - b. Implement an appropriate visual scan? Yes \_\_\_\_\_  
No explain \_\_\_\_\_
  
3. Did you observe crews using the TCAS/TRACKS Mode? How, Where, and Why was it used?
  
4. Please comment on any aspect of TCAS which you feel needs attention.

Date \_\_\_\_\_

TCAS PILOT QUESTIONNAIRE

FLIGHT NUMBERS \_\_\_\_\_

Flight crew experience level for TCAS:

	PIC	F/O	S/O
Less than 5 flights	___	___	___
5 - 10 flights	___	___	___
More than 10 flights	___	___	___

Did TCAS traffic information correspond to actual visual sightings?

Yes \_\_\_\_\_ No \_\_\_\_\_ No Visual Contact \_\_\_\_\_

Did you use TCAS/Track as an aid to locate traffic during ATC advisories?

Yes \_\_\_\_\_ No \_\_\_\_\_ (Please comment on phase of flight)

Describe any problems in system operation, display interpretation, or training. (Use back side if needed.)

\*\*\*\*\*

If you had a TCAS WARNING!

1. What was the TCAS recommended avoidance maneuver?
2. Did you follow it?
3. Based upon all other information available, did the TCAS WARNING:
  - a. Appear proper for resolution of the conflict? Yes \_\_\_\_\_  
No (explain) \_\_\_\_\_
  - b. Tell you what you expected?
  - c. Was it necessary? (explain)

Please assist the observer in reconstructing and diagraming the events leading to a TCAS WARNING. Include additional information with your questionnaire or feel free to call ARINC Research to discuss TCAS. Toll free WATS line is 1-800-638-4908 ext. 4712 or 4729.

\*\*\*\*\*

#### OPTIONAL

Diagram the encounter situation which caused the WARNING. Use the same symbols as those displayed on the CRT. Add letters to the triangles to denote the sequence. See example in observer book.

<u>Location of Target</u>	<u>Symbols</u>
a. Caution occurred	Descent of Climb
b. Warning occurred	Relative Altitude
c. Visual Contact	Basic Symbol
d. End of Advisory	

## APPENDIX D

### TCAS WARNING SUMMARY

This appendix presents summaries and data for the 48 encounters that resulted in the issuance of TCAS Warnings during the Phase II evaluation.

With the exception of those encounters in which no data were recorded by the TCAS data recording system, each encounter is accompanied by two figures prepared from the recorded data. When recorded data are not available, the encounter geometry reported with the observer data are included. The first plot from the recorded data shows the relative bearing and range of the intruder aircraft throughout the encounter. The data are presented in a plan view; a turn by either aircraft causes a change in the relative bearing of the two aircraft. Each symbol on the chart represents a one-second update of the data.

The second plot generated from the recorded data is an x-y plot that contains several graphs. On these plots, elapsed time from the start of the encounter is plotted along the x-axis. The following types of data are plotted in three graphs whose values are shown on the y-axis:

- The top plot shows the current altitude of the TCAS aircraft, ZOWN, and the threat aircraft, ZINT, versus system time. The scale for the altitude plot, in feet, is on the left vertical axis. The range between the two aircraft, R, is also plotted. The scale for R, in nm, is on the right vertical axis.
- The middle plot is a plot of current altitude separation, A, and projected altitude separation, VMD, versus system time. The thresholds for threat detection, ZTHR, and positive/negative advisory selection, ALIM, are both plotted as dashed lines, with their values shown in the legend.
- The bottom plot shows the range tau (TAUR) and vertical tau (TAUV) values plotted as the ordinates. The thresholds associated with TAUR and TAUV, TRTHR, and TVRHR, respectively, are shown as dashed lines and their values are printed in the legend.



At the top of the plot is a representation of the TCAS Warnings generated during the encounter. An arrow indicates a CLIMB or DESCEND advisory; an arrow with an X on the shaft indicates a DO NOT CLIMB or DO NOT DESCEND advisory; an arrow with bars on the shaft represents a LIMIT CLIMB or LIMIT DESCENT advisory, with three bars signifying 500 fpm, two bars 1,000 fpm, and one bar 2,000 fpm.

A vertical line is drawn on the plots to indicate when the Warning was issued.

## 1. TCAS WARNING 1

On March 20, 1987, the TCAS aircraft, operating as Piedmont Flight 135 was en route to Newark, New Jersey, from Boston, Massachusetts. At approximately 0216Z the aircraft was 42 miles to the northwest of Newark, near the Sparta VOR. ATC had cleared the aircraft to descend from 12,500 feet to 7,000 feet. Prior to any TCAS caution or ATC advisory, and while establishing their descent, the aircrew visually acquired traffic at approximately their 10 o'clock position. Shortly after visual acquisition, a TCAS Caution was issued with the intruder at approximately 11 o'clock and outside of 6 miles. The Caution showed the intruder was in level flight with a relative altitude 700 feet below that of Flight 135. The CRT symbol tracked from the 11 o'clock to the 5 o'clock position, and when the intruder came within 2 miles of the TCAS aircraft, a Warning was issued. Flight 135 was still descending at the time of the Warning, which advised the pilot to LIMIT VERTICAL RATE - DO NOT DESCEND. The pilot flying the aircraft responded by leveling the aircraft for approximately 10 seconds, after which the Warning cleared. The pilot then resumed the original descent profile. An ATC traffic advisory was issued shortly after the initial Warning. Flight conditions at the time were night, VMC, with visibility greater than 20 miles.

The observer notes on the encounter are shown in Figure D-1.

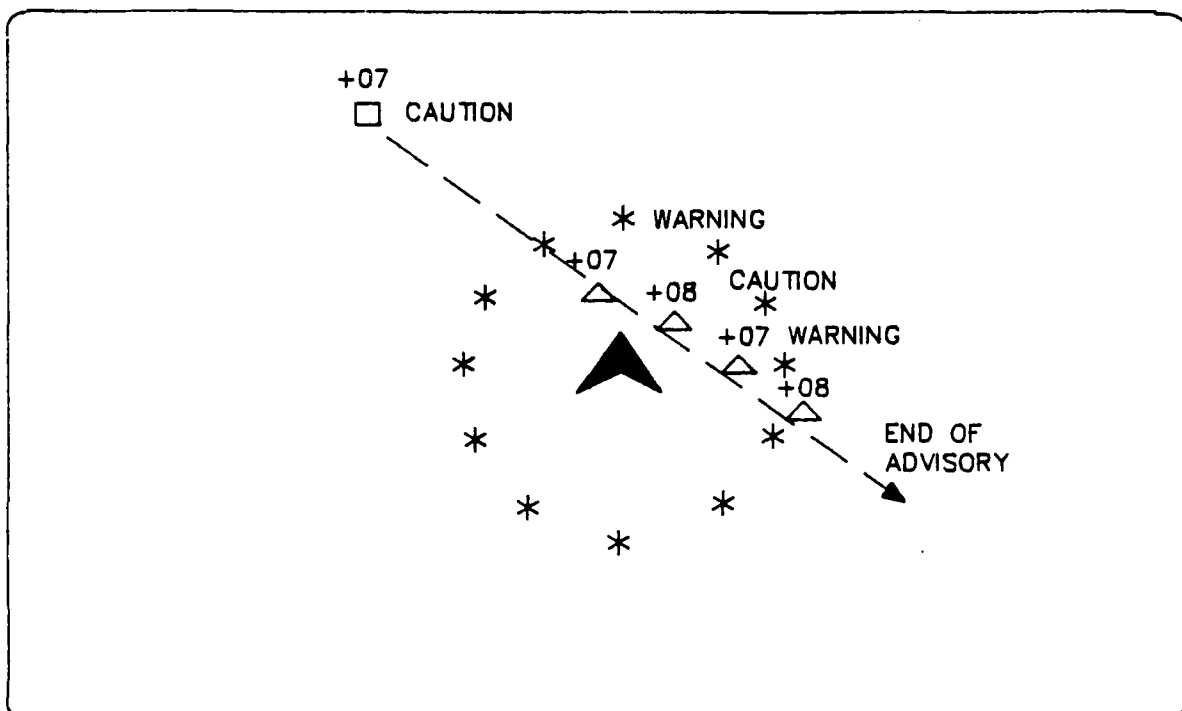
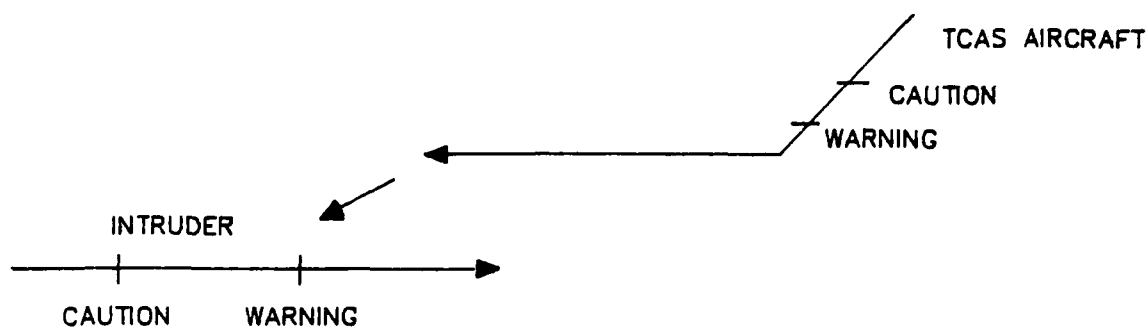


FIGURE D-1  
TCAS WARNING 1

## 2. TCAS WARNING 2

On March 22, 1987, Piedmont 75 was en route from Boston, Massachusetts, to Charlotte, North Carolina. At approximately 1108Z the aircraft was descending into the Charlotte terminal area (leaving 4,000 feet for 2,500 feet) when a TCAS Caution was issued. The initial Caution showed the intruder aircraft at approximately 2 o'clock, 1,200 feet below Flight 175, and climbing. When the intruder was at approximately 3 o'clock and 300 feet above, TCAS issued a Warning that instructed the pilot to descend. Since the aircraft was already established in a 500 fpm descent, the pilot merely increased his descent rate to 1,500 fpm. The crew gained visual contact with the intruder at this time. When the Warning cleared, the pilot resumed a shallower descent rate. Flight conditions at the time were day, VMC, with visibility approximately 20 miles.

The observer concluded that the Warning was probably not necessary, since the intruder was already 300 feet above and passing abeam of Flight 75, the closest point of approach was greater than 2 miles, and Flight 75 was already established in a descent.

Figure D-2 show the observer's notes from the encounter, and Figures D-3 and D-4 present the recorded data on the encounter.

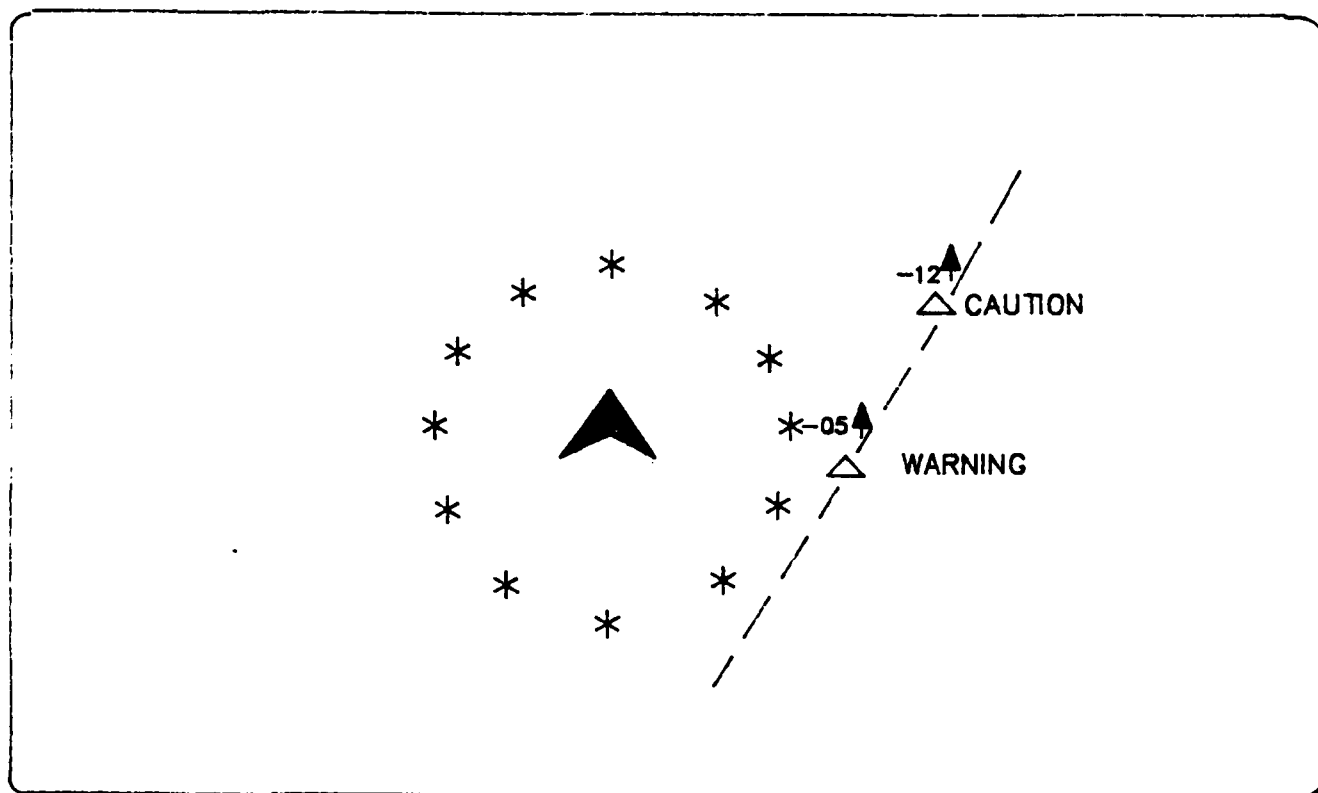
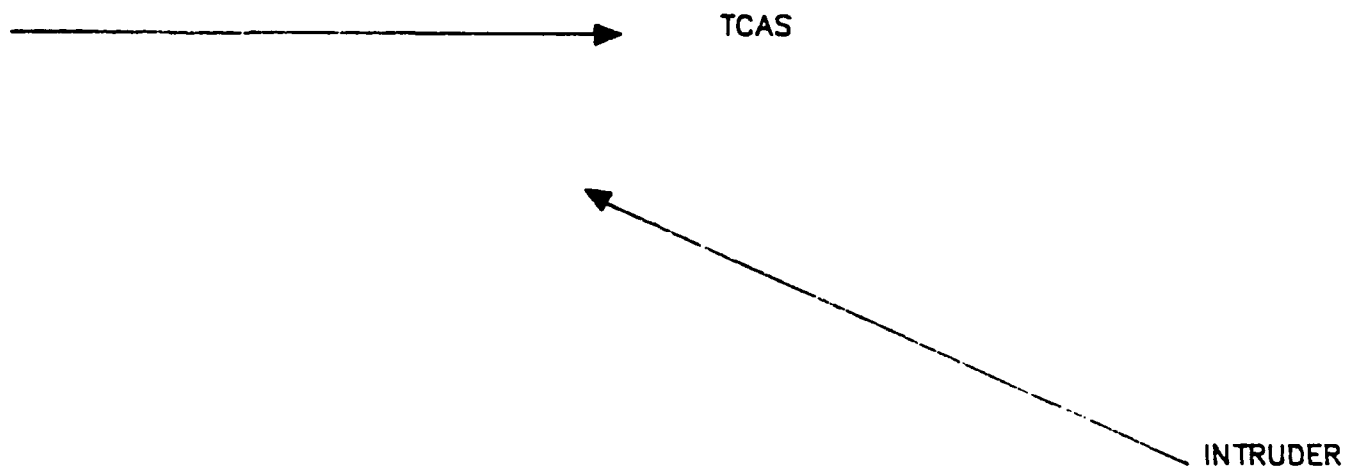


FIGURE D-2

TCAS WARNING 2: OBSERVER DATA

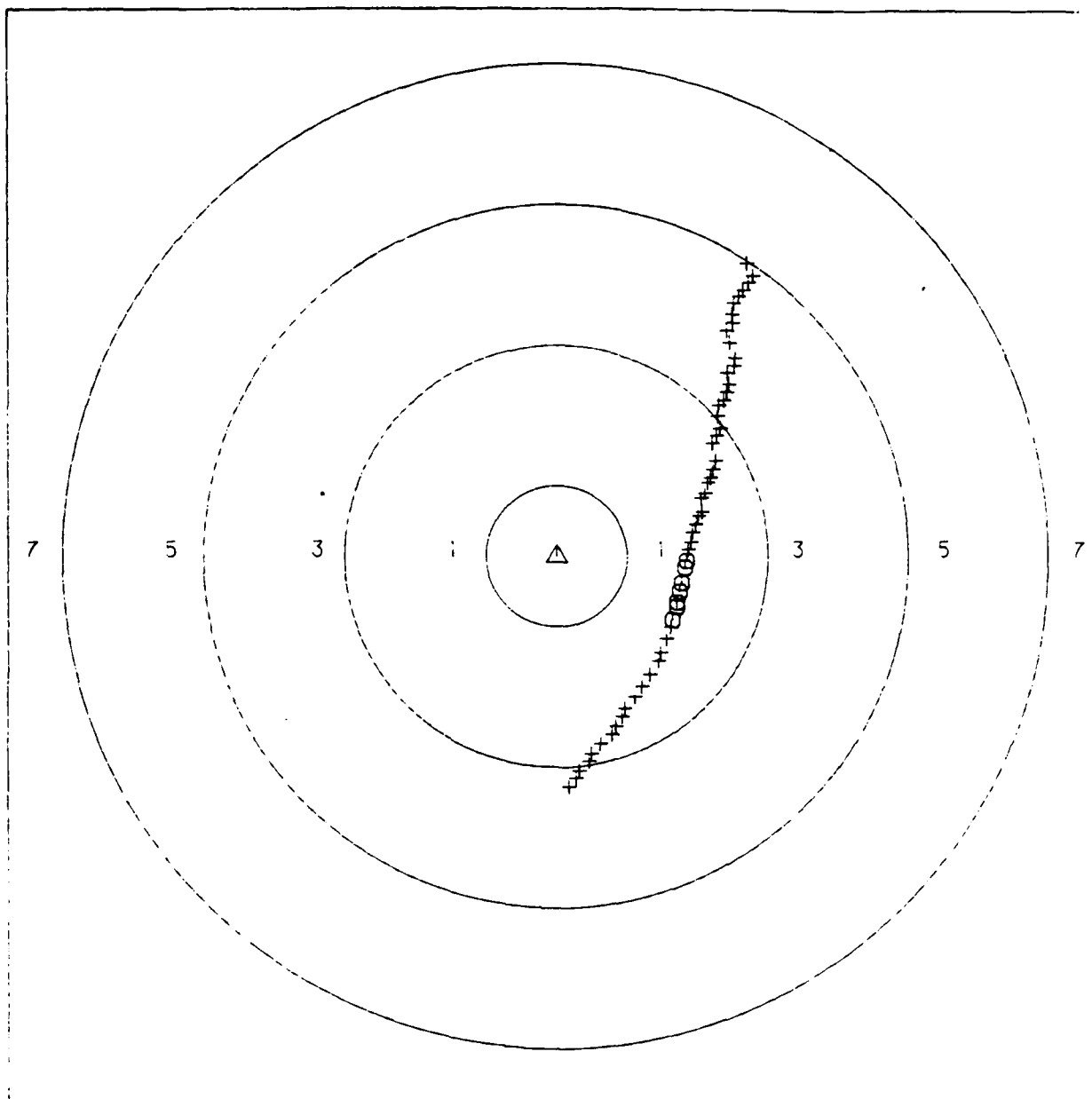


FIGURE D-3

TCAS WARNING 2: BEARING PLOT

FLIGHT RA .....  
 MC SIM RA .....

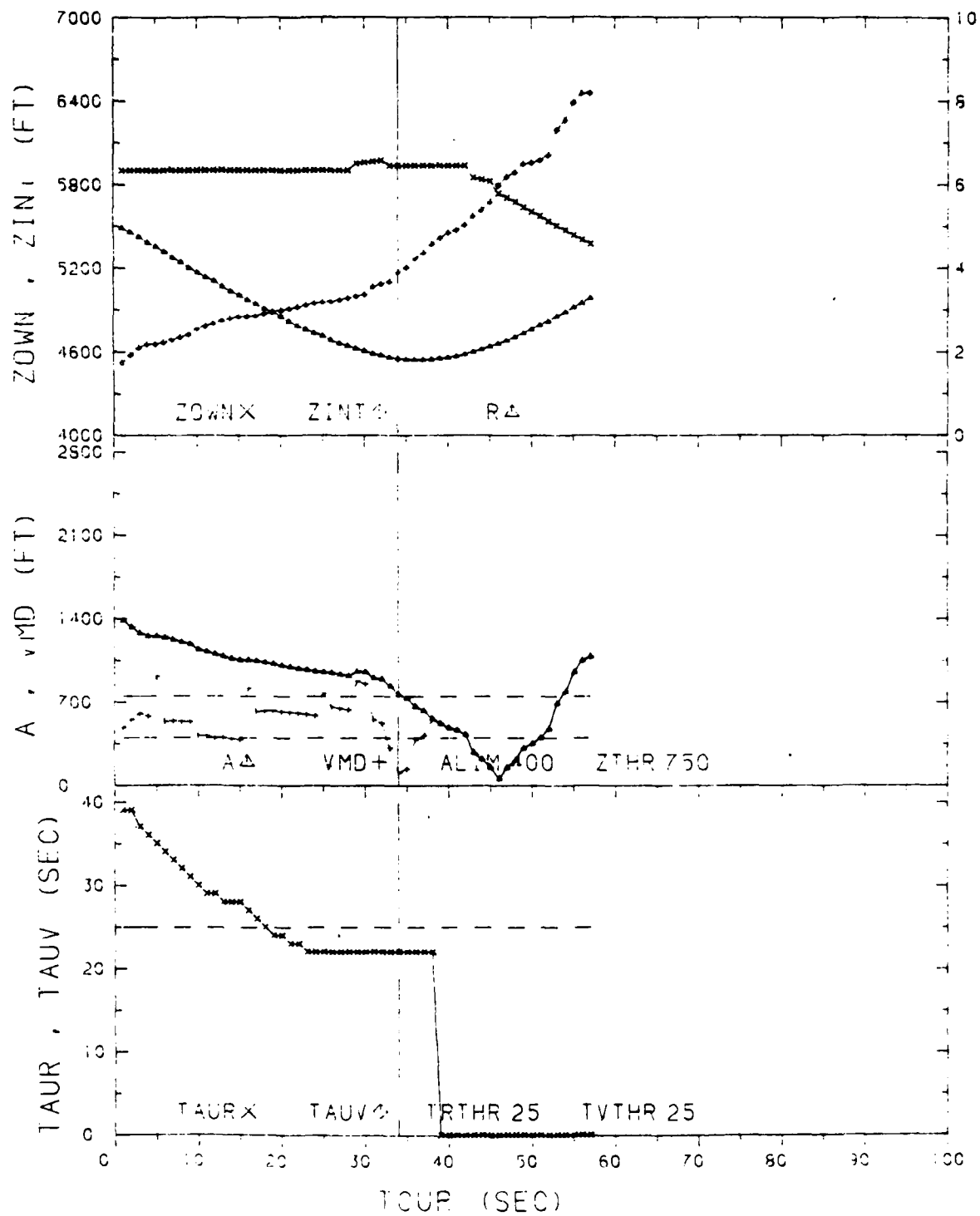


FIGURE D-4

TCAS WARNING 2: PARAMETERS

### 3. TCAS WARNING 3

TCAS Warning 3 occurred when there was no observer on the TCAS aircraft. Figures D-5 and D-6 show the recorded data from this encounter.



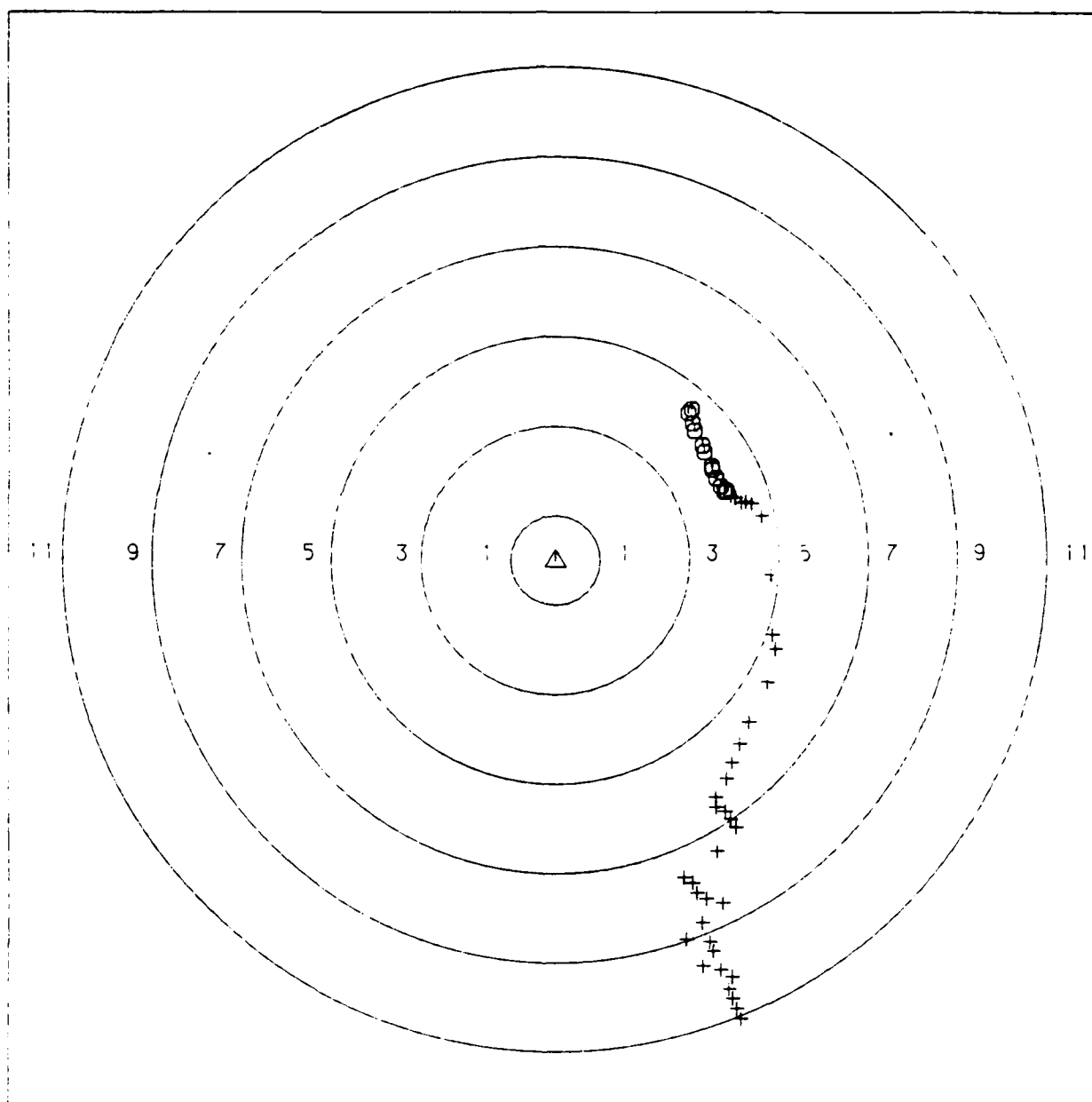


FIGURE D-5

TCAS WARNING 3: BEARING PLOT

FLIGHT RA



MC SIM RA

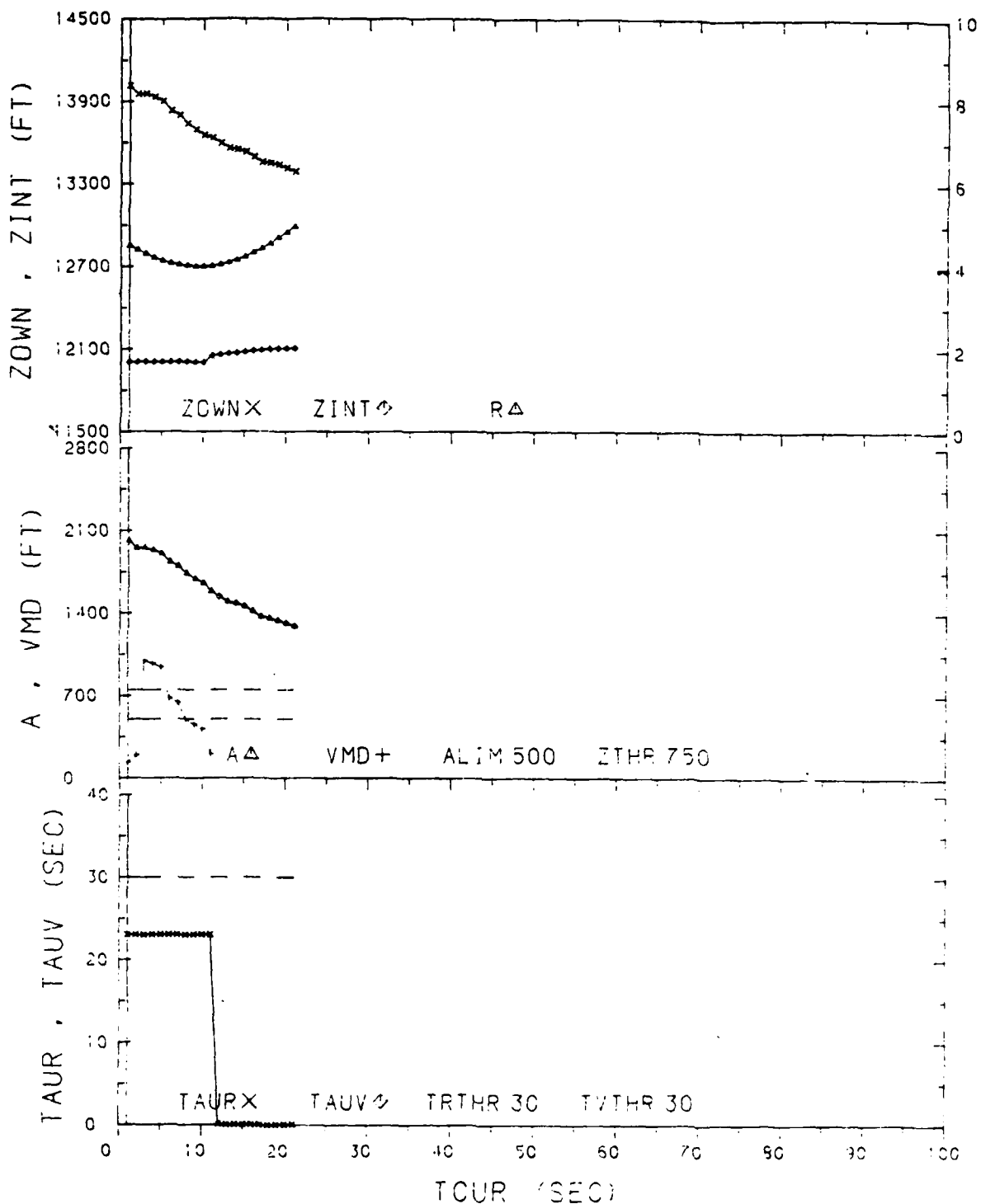


FIGURE D-6

TCAS WARNING 3: PARAMETERS

#### 4. TCAS WARNING 4

On March 25, 1987, Piedmont Flight 121 from Charlotte, North Carolina, to Philadelphia, Pennsylvania, was entering the Philadelphia TCA. At approximately 2247Z, ATC cleared the aircraft to descend from its assigned altitude of 9,500 feet to 8,000 feet. Flight conditions at the time were day, VMC, with unrestricted visibility. ATC advised Flight 121 of traffic at 12 o'clock just before TCAS generated a Caution. The Caution showed the intruder at 12 o'clock, 900 feet below, and in level flight. The crew acquired the intruder visually and then was instructed by ATC to level off (prior to reaching the assigned altitude of 8,000 feet). As the aircraft was leveling off, TCAS issued a DO NOT DESCEND Warning and showed the intruder at 12 o'clock, 700 feet below, and inside of two miles. No response was required by the aircrew, since ATC had already issued the level-off clearance.

The recorded data for this encounter are shown in Figures D-7 and D-8.

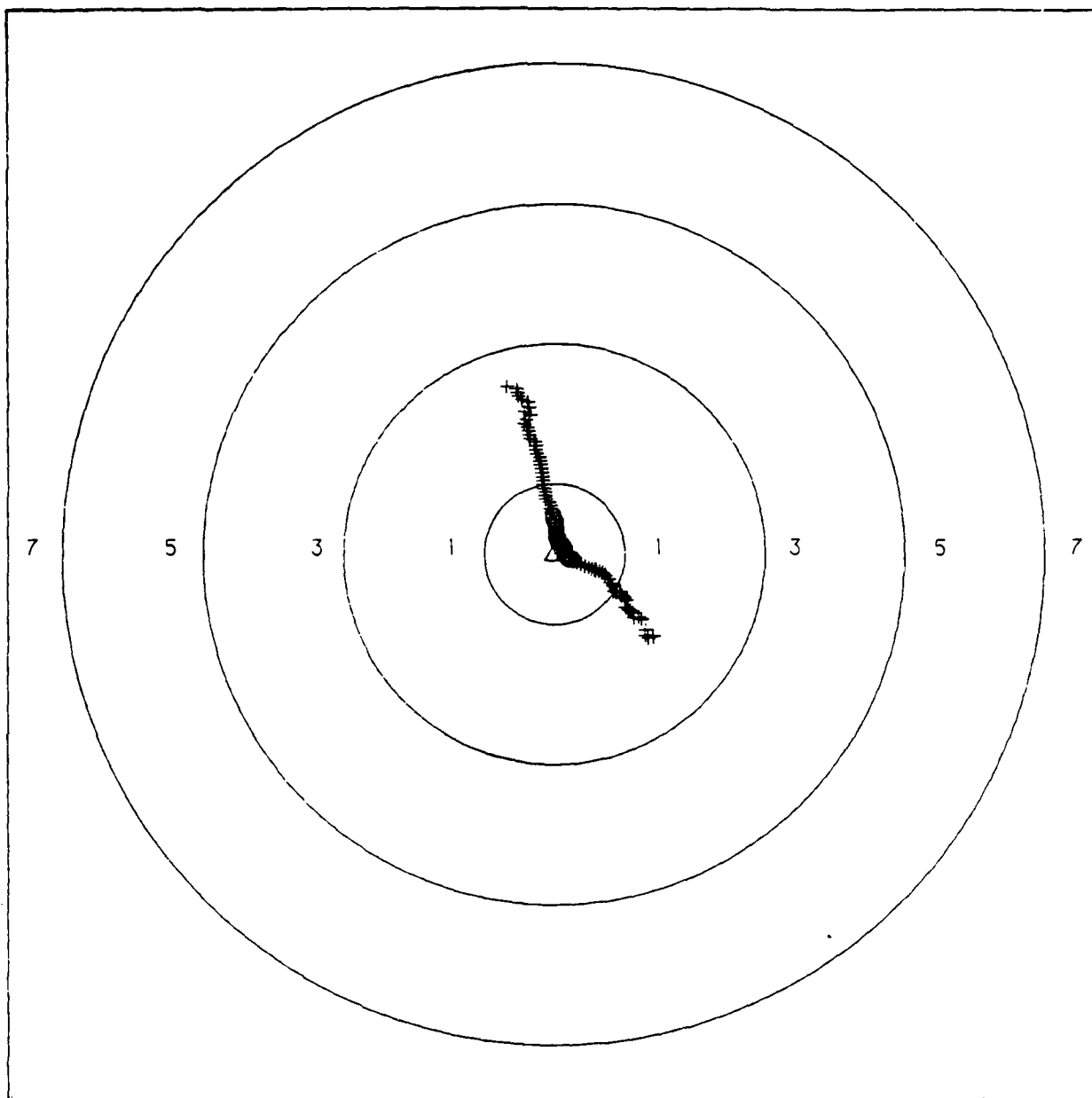


FIGURE D-7  
TCAS WARNING 4: BEARING PLOT

FLIGHT RA

MC SIM RA

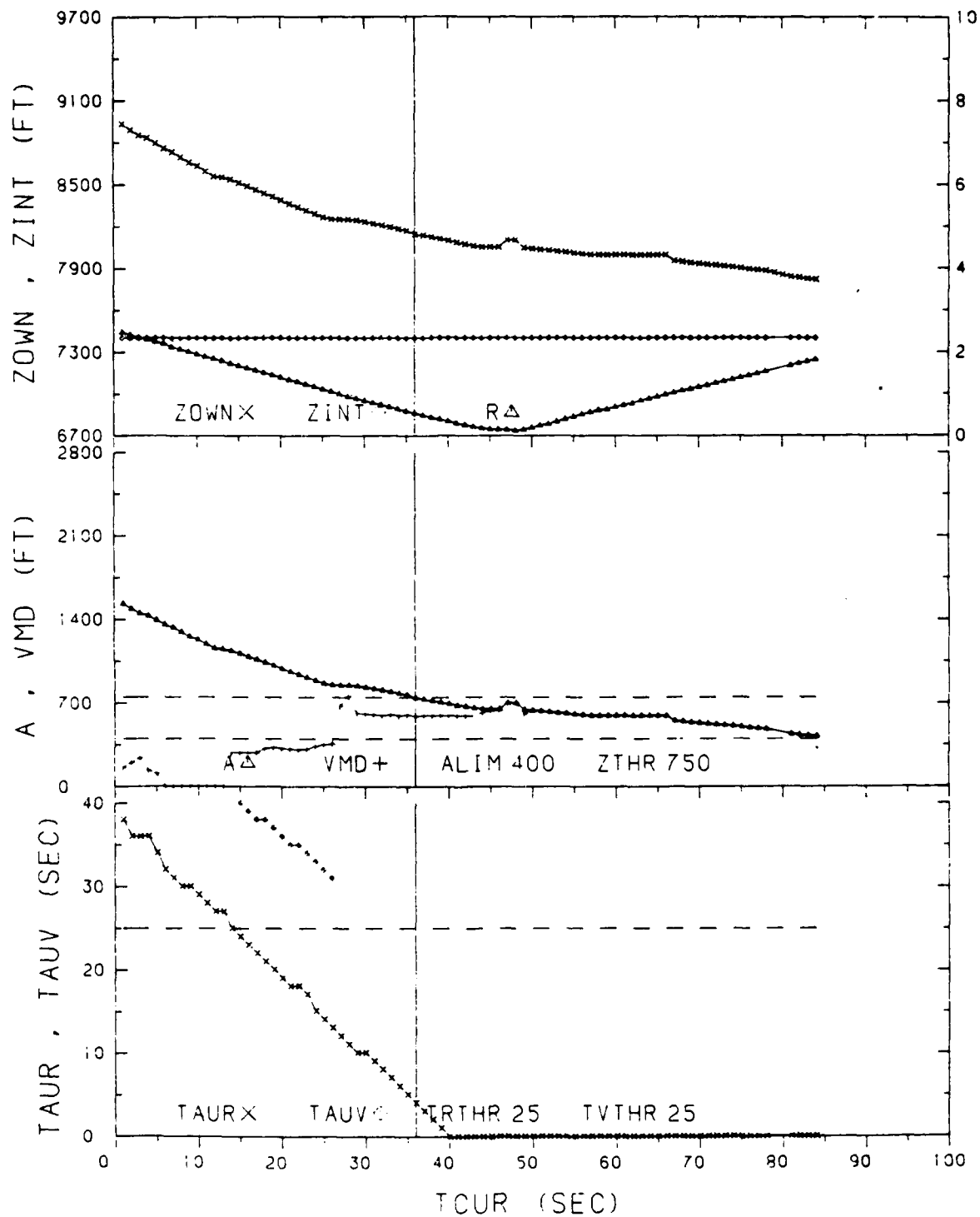


FIGURE D-8

TCAS WARNING 4: PARAMETERS

## 5. TCAS WARNING 5

On April 7, 1987, Piedmont Flight 79 was crossing LEEON intersection on the Charlotte (CLT) 068 degree radial at 44 DME en route from Norfolk, Virginia, to Charlotte, North Carolina. Flight conditions were day, VMC, with visibility greater than 15 miles. Flight 79 was established in a 2,700 fpm descent from 14,500 feet to 12,000 feet when it received a TCAS warning to LIMIT VERTICAL RATE, DO NOT DESCEND GREATER THAN 2,000 FPM. (This Warning was not preceded by a caution). The pilot at the controls decreased the aircraft's vertical speed to approximately 1,800 fpm until the encounter cleared. The intruder's initial position was 2 o'clock, 1,100 feet below, in level flight. When the Warning cleared, the intruder was at 4 o'clock, 800 feet below, in level flight.

The observer notes on the encounter geometry are shown in Figure D-9. There are no automatically recorded data available for this encounter.

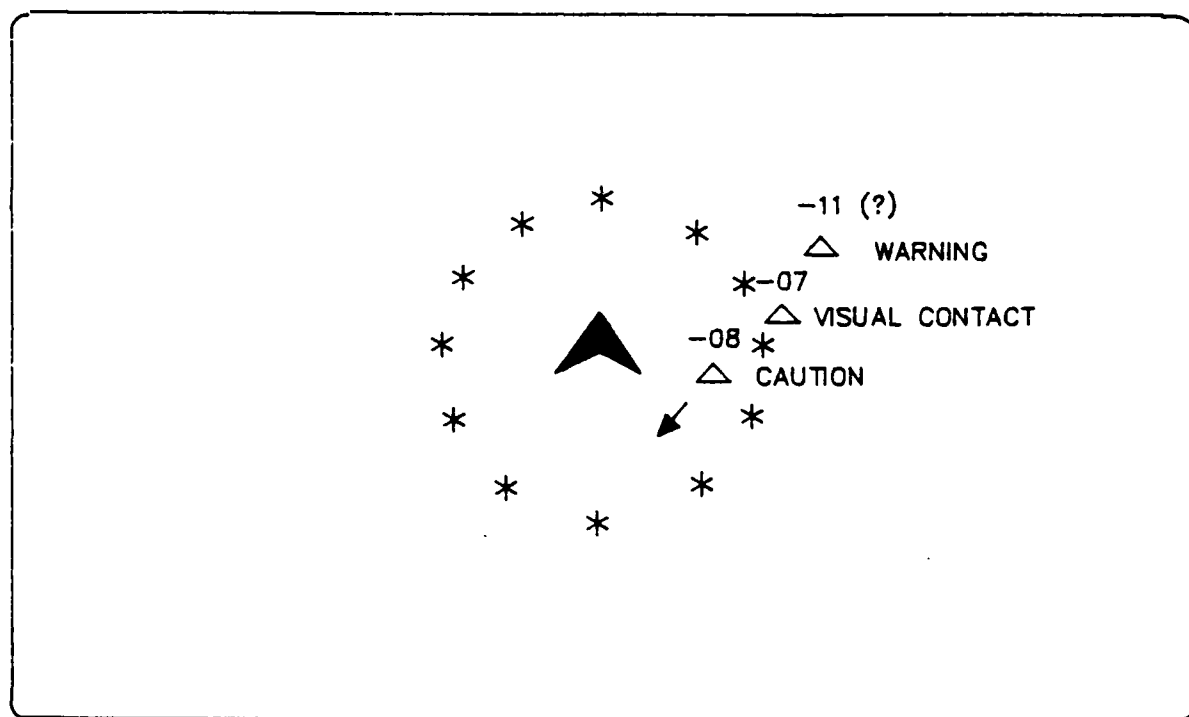
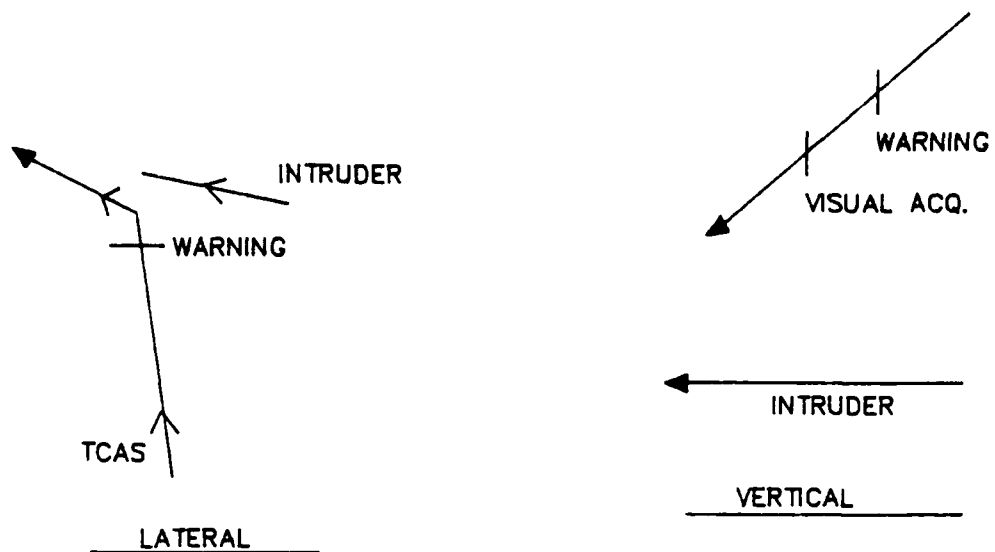


FIGURE D-9  
TCAS WARNING 5

## 6. TCAS WARNING 6

On April 7, 1987, the TCAS aircraft was operating as Piedmont Flight 79 en route from Charlotte, North Carolina, to Dallas-Ft. Worth, Texas. At approximately 1822Z the aircraft was on the DFW 030 degree radial at 11 DME and was descending to its assigned altitude of 11,000 feet. The encounter began with a TCAS Caution showing the intruder aircraft at the 12 to 1 o'clock position, 1,200 feet below Flight 79, and out of the CRT display range. The crew gained visual contact with the traffic and determined that Flight 79 would pass above and behind it. Just after the TCAS aircraft leveled off at 11,000 feet, a DESCEND warning was issued. The intruder aircraft was at 1 o'clock, 700 feet below, and level. Since the Captain had the intruder in sight, he elected to ignore the Warning, and a TCAS INVALID was then issued. The encounter ended with the intruder aircraft at 9 o'clock, with 1.5 miles of lateral separation and 800 feet of vertical separation indicated. Flight conditions were day, VMC, with visibility 15 miles. No ATC advisories were issued during this encounter.

This Warning is discussed in detail in Chapter Five of this report.



## 7. TCAS WARNING 7

On April 7, 1987, Piedmont Flight 94 was en route to Charlotte, North Carolina, from Dallas-Ft. Worth, Texas. The aircraft was maneuvering in the Charlotte terminal area. Flaps were set at more than 15 degrees, and the landing gear was up. Flight conditions were day, VMC, with visibility reported at 10 miles. At 2141Z, Charlotte approach advised Flight 94 of traffic (a Cessna 172) at 12 o'clock and 2,500 feet MSL. As the TCAS aircraft descended through 3,600 feet for its assigned altitude of 3,000 feet, TCAS issued a Caution showing the intruder in the same area as indicated by ATC and 1,000 feet below. ATC cleared Flight 94 for a visual approach to runway 36L at Charlotte but instructed the pilot to remain above 3,000 feet until further advised. With the intruder approximately 2 miles from Flight 94, visual acquisition was gained and reported to ATC. With the intruder's range inside of 2 miles and TCAS showing 700 feet of vertical separation, a LIMIT VERTICAL RATE - DO NOT DESCEND warning was issued. This complemented the instructions already received from Charlotte approach control, and the aircraft had already begun to level off at its 3,000-foot clearance. The Warning cleared with the intruder at 3 o'clock with approximately 1 mile lateral separation and 700 feet vertical separation.

No TCAS data were recorded for this encounter. The observer notes on the encounter's geometry are shown in Figure D-10.

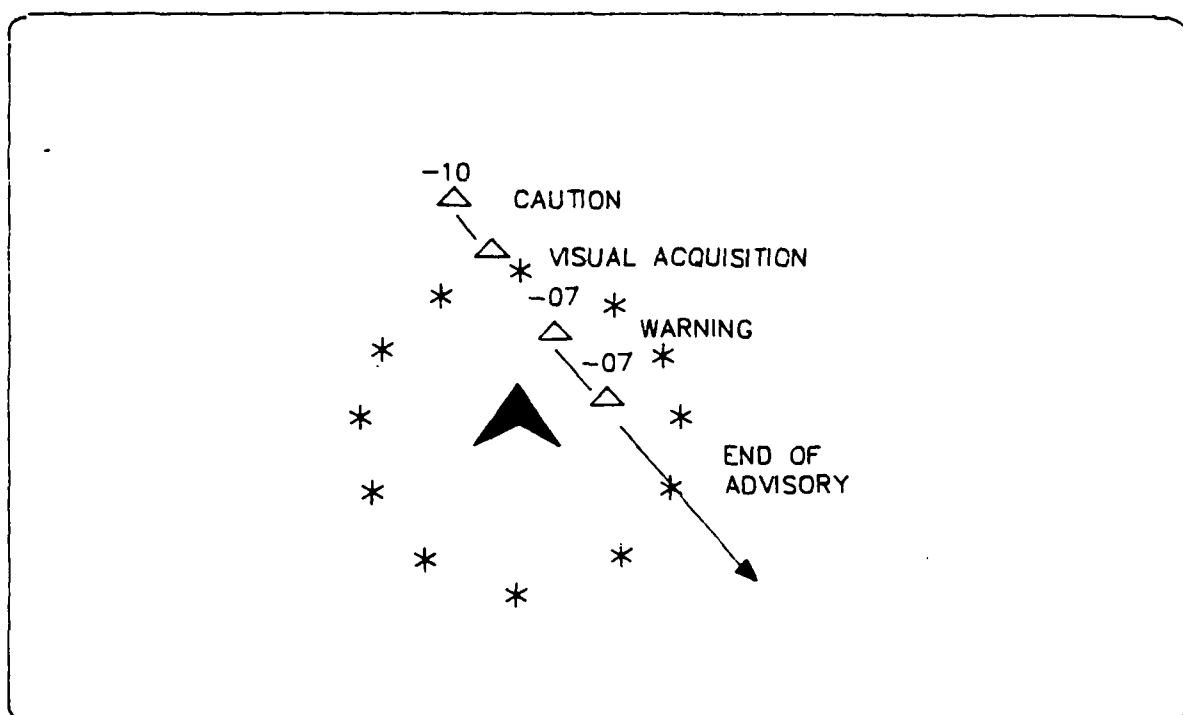
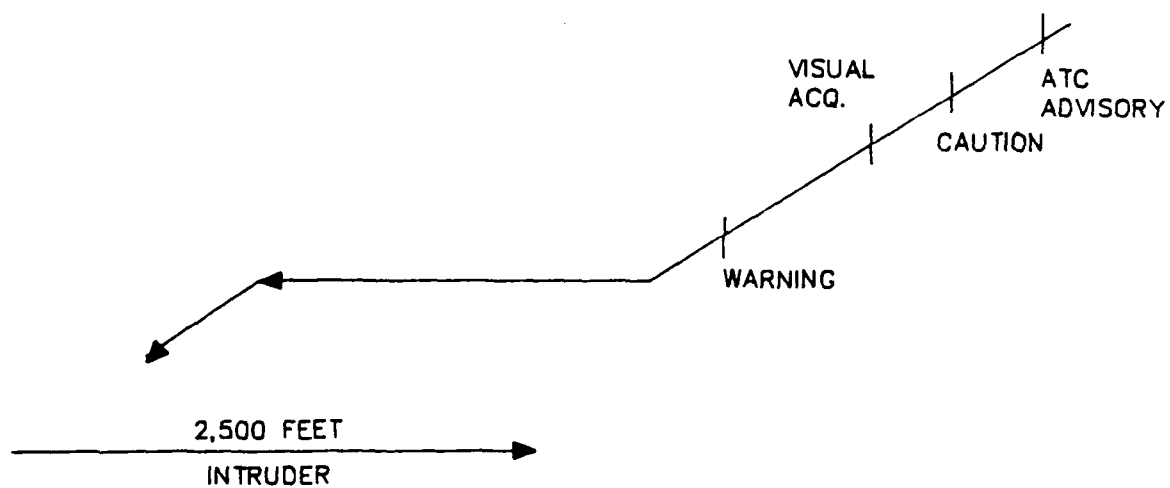


FIGURE D-10

TCAS WARNING 7

## 8. TCAS WARNING 8

On April 8, 1987, the TCAS aircraft was operating as Piedmont Flight 85 on a scheduled flight from Baltimore, Maryland, to Orlando, Florida. At approximately 1330Z, Flight 85 was 20 DME south of the Nottingham (OTT) VOR on the 184 degree radial. The aircraft was established in a 2,000 fpm climb to its assigned altitude of FL 240, when ATC advised the crew of traffic at 12 o'clock and level at 17,500 feet, with altitude readout not verified. The intruder aircraft was in level flight on a reciprocal heading. Shortly after the ATC advisory, a TCAS Caution showed the intruder to be 1,100 feet above Flight 85 at 12 o'clock but out of CRT display range. The crew immediately asked ATC for an updated position on the traffic. The crew was then able to gain visual contact with the intruder and continued its climb. When it was passing 16,800 feet, with the intruder aircraft approximately 3 miles from and 500 feet above the TCAS aircraft, a Warning was generated that advised the crew to CLIMB. Since they were already established in a 2,000 fpm climb, no action was necessary and the existing climb rate was maintained. The crew tracked the intruder as it passed down the left side of and below Flight 85. Flight conditions at the time were day, VMC, with visibility 20 miles.

The observer noted that immediately after the initial ATC advisory and before the Caution was generated, the crew made use of the TCAS/TRACKS function in an attempt to obtain additional position information on the intruder. Unfortunately, the intruder was still outside of that mode's display parameters. The observer notes on this encounter are shown in Figure D-11.

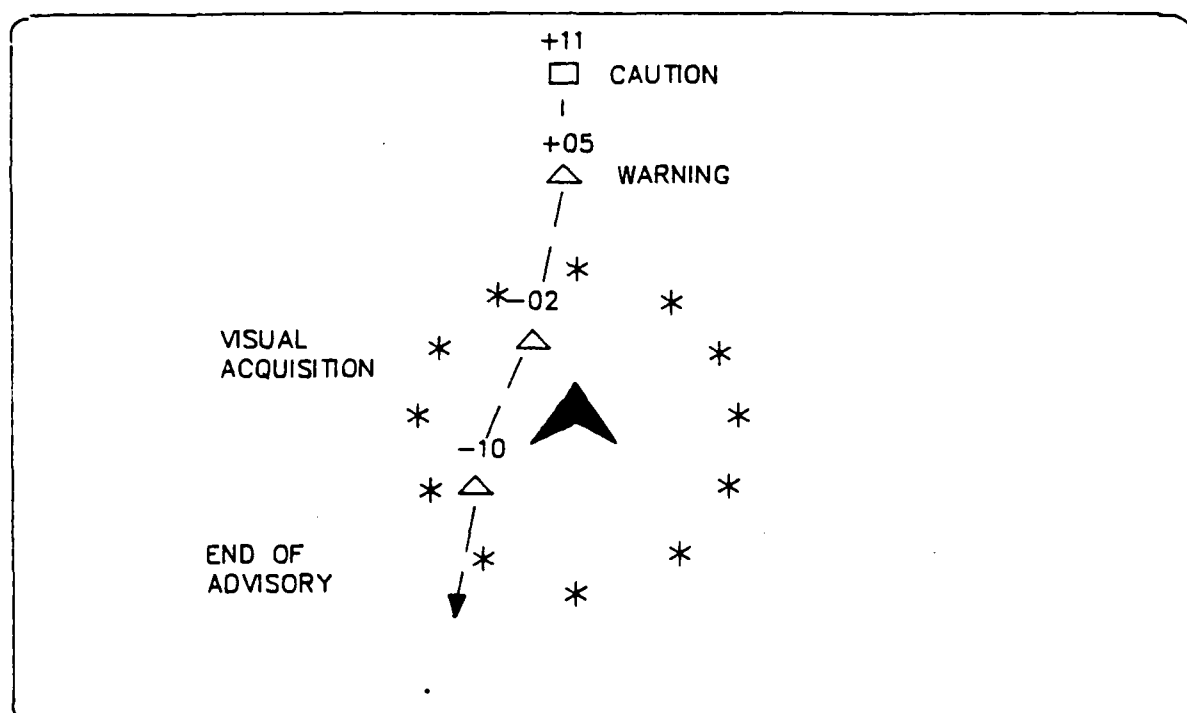
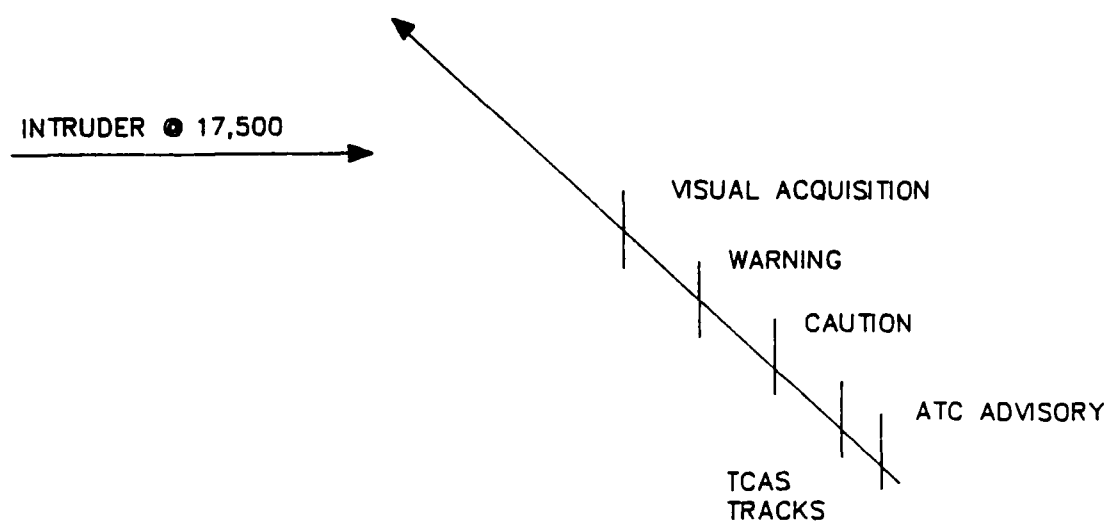


FIGURE D-11  
TCAS WARNING 8

## 9. TCAS WARNING 9

On April 10, 1987, Piedmont Flight 74 was en route to Tampa, Florida, from Miami, Florida. The aircraft was commencing its approach into Tampa and was descending through 11,000 feet. At approximately 1830Z with Flight 74 at 31 DME from St. Petersburg on the 125 degree radial, ATC issued a traffic advisory. An intruder aircraft was below Flight 74 climbing through 9,000 feet to its assigned altitude of 9,500 feet and headed in the opposite direction. Shortly thereafter, a TCAS Caution was issued showing the intruder at approximately 12 o'clock. With the intruder at approximately 2 miles and 12 o'clock, a Warning was issued advising the aircrew to LIMIT VERTICAL RATE - DO NOT DESCEND. No action was taken by the crew, since the traffic had been visually acquired. Flight conditions at the time were day, VMC, although the observer stated that the in-flight visibility was only 2 to 3 miles in haze.

The observer noted that the Warning appeared proper for the situation, although there was some confusion among the crew members as to what was occurring. Observer notes on the encounter are shown in Figure D-12.

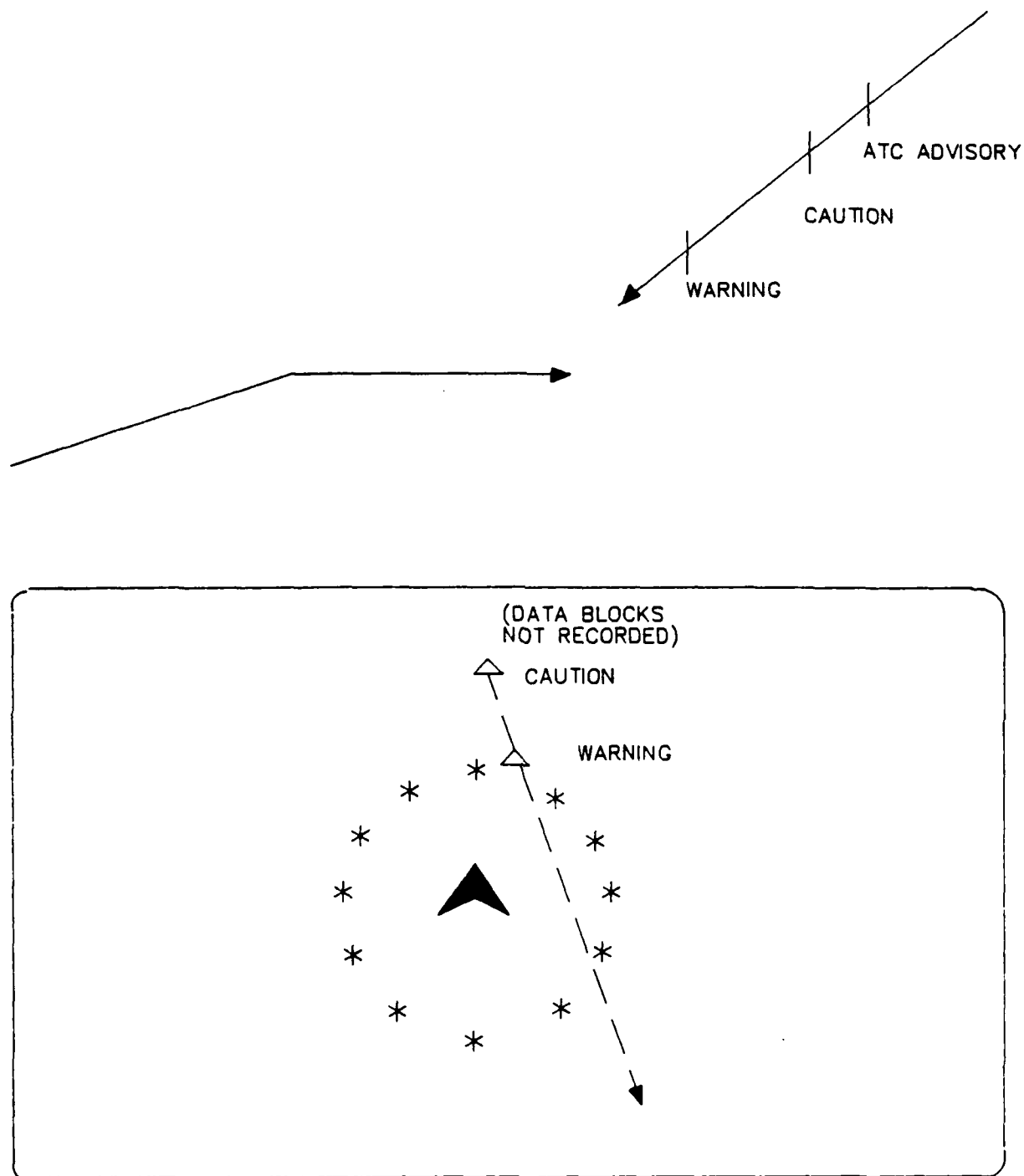


FIGURE D-12  
TCAS WARNING 9

#### 10. TCAS WARNING 10

On April 15, 1987, Piedmont Flight 63 en route from Washington, D.C., was maneuvering for final approach in the Charlotte, North Carolina, terminal area. Flight conditions at the time were marginal VMC with in-flight visibility approximately 3 miles in haze. Flight 63 was cleared for a visual approach to runway 36R and commenced a turn from base leg to final. ATC advised the crew of traffic on the parallel approach course (36L). Within 5 seconds of the ATC advisory, TCAS generated a caution showing the traffic at 12 o'clock, 300 feet below. The crew used the CRT information to visually acquire the intruder. A Warning followed advising the crew to CLIMB. Since the traffic was in sight and the crew knew its intentions, the Warning was not followed. Additionally, the pilots stated that following the climb command would more than likely have resulted in a missed approach.

This encounter is discussed in detail in Chapter Five of this report.

## 11. TCAS WARNING 11

Piedmont Flight 57 was en route to Tampa, Florida, from Baltimore, Maryland, on April 16, 1987. At 1804Z the aircraft was approximately 10 miles north of Tampa and level at 10,000 feet when a TCAS Caution was generated. The Caution showed the intruder aircraft at 12 o'clock and 2,100 feet below the TCAS aircraft. Shortly after the Caution was issued, ATC advised Flight 57 of the traffic, a B-737 departing TPA and crossing left to right. Flight conditions at the time were day, VMC, with visibility reported at 15 miles. As the crew acquired the intruder visually, a DESCEND warning was issued by TCAS. Flight 57 had been previously cleared by ATC to descend to 2,000 feet, but the pilot elected to maintain his present altitude until after CPA, and the two aircraft began diverging. Visual separation was maintained throughout the encounter.

No TCAS data were recorded during this encounter. Further analysis of the encounter using TPA TRACON tapes revealed an altitude crossing situation. The DESCEND command issued by TCAS was correct for the circumstances and would have provided safe separation had the crew elected to follow it. The details of this encounter are discussed in Chapter Five.



## 12. TCAS WARNING 12

On April 18, 1987, the TCAS aircraft, operating as Piedmont Flight 115 was 30 miles south of Grand Rapids, Michigan, en route from Dayton, Ohio, and leveling off at its assigned altitude of 10,000 feet. The flight conditions were day, VMC, with visibility approximately 10 miles and a broken cloud layer just below 10,000 feet. At 1925Z ATC advised the crew of traffic slowly climbing through 9,300 feet heading in the opposite direction. Almost immediately after the ATC call, TCAS generated an advisory showing an intruder at 11 o'clock, 1,000 feet below and climbing, and at a range of approximately 2 miles. At a range of approximately 1 mile, TCAS issued a Warning to CLIMB and showed the intruder at 10 o'clock, 500 feet below, and climbing. Without visual contact (the intruder aircraft was below the cloud layer), the crew advised ATC of the situation and requested a higher altitude. ATC issued a clearance to climb back to 12,000 feet, and as the aircraft climbed, the CLIMB command was downgraded to LIMIT VERTICAL RATE - DO NOT DESCEND. The encounter cleared with the intruder passing down the left side of the aircraft to the 7 o'clock position.

The ATC controller involved in the encounter later stated that Flight 115's request for a higher altitude could be accommodated in this case because traffic was light and it was a Saturday afternoon. If this situation had occurred during a period of heavier traffic, there might have been an impact on the ATC system and the request might not have been honored.

The TCAS data for this encounter are shown in Figures D-13 and D-14.

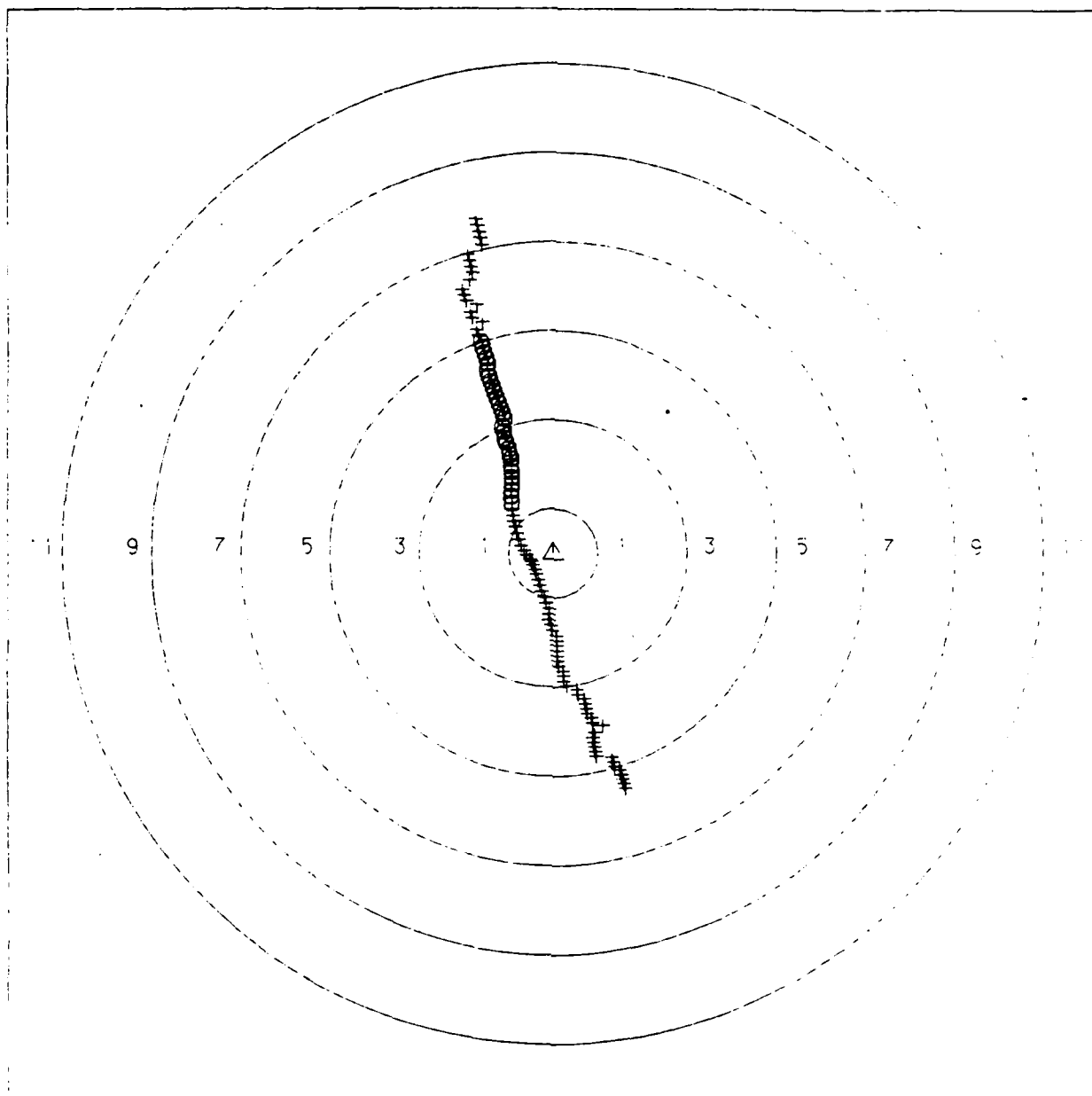


FIGURE D-13

TCAS WARNING 12: BEARING PLOT

FLIGHT PA

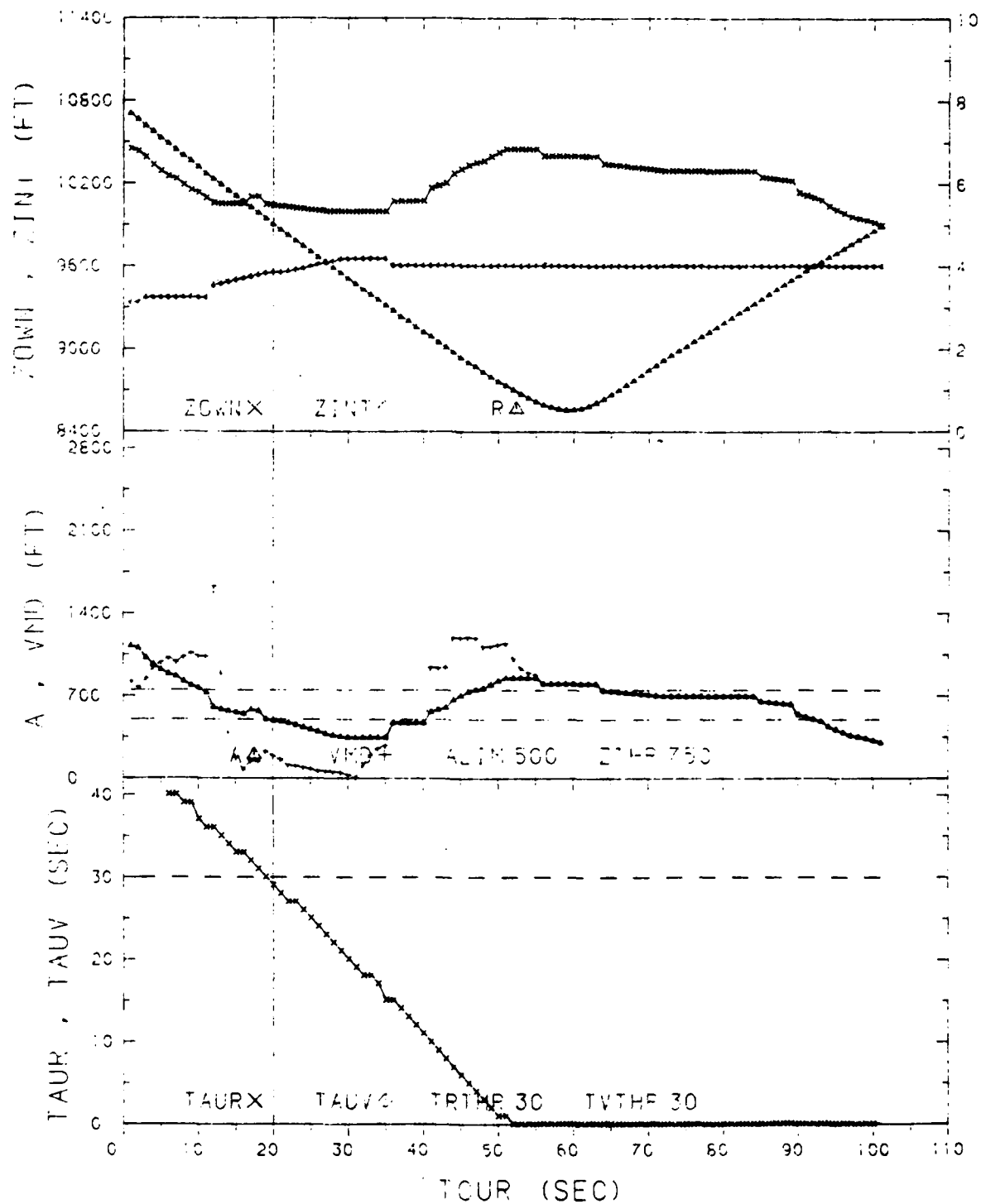


FIGURE D-14

TCAS WARNING 12: PARAMETERS

### 13. TCAS WARNING 13

TCAS Warning 13 was unobserved. The recorded data for this encounter are shown in Figures D-15 and D-16.

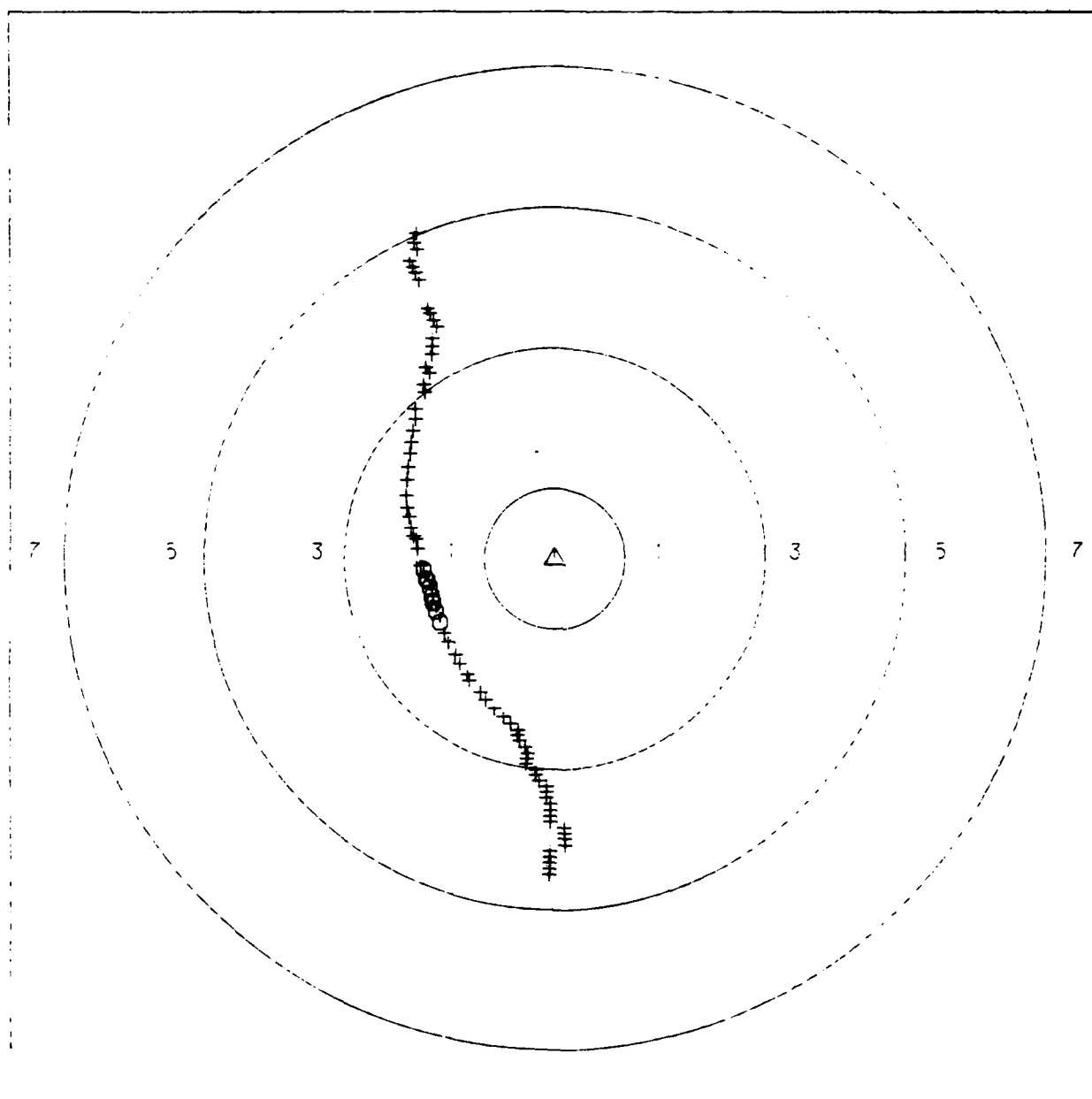


FIGURE D-15

TCAS WARNING 13: BEARING PLOT

FLIGHT RA  
MC SIM RA

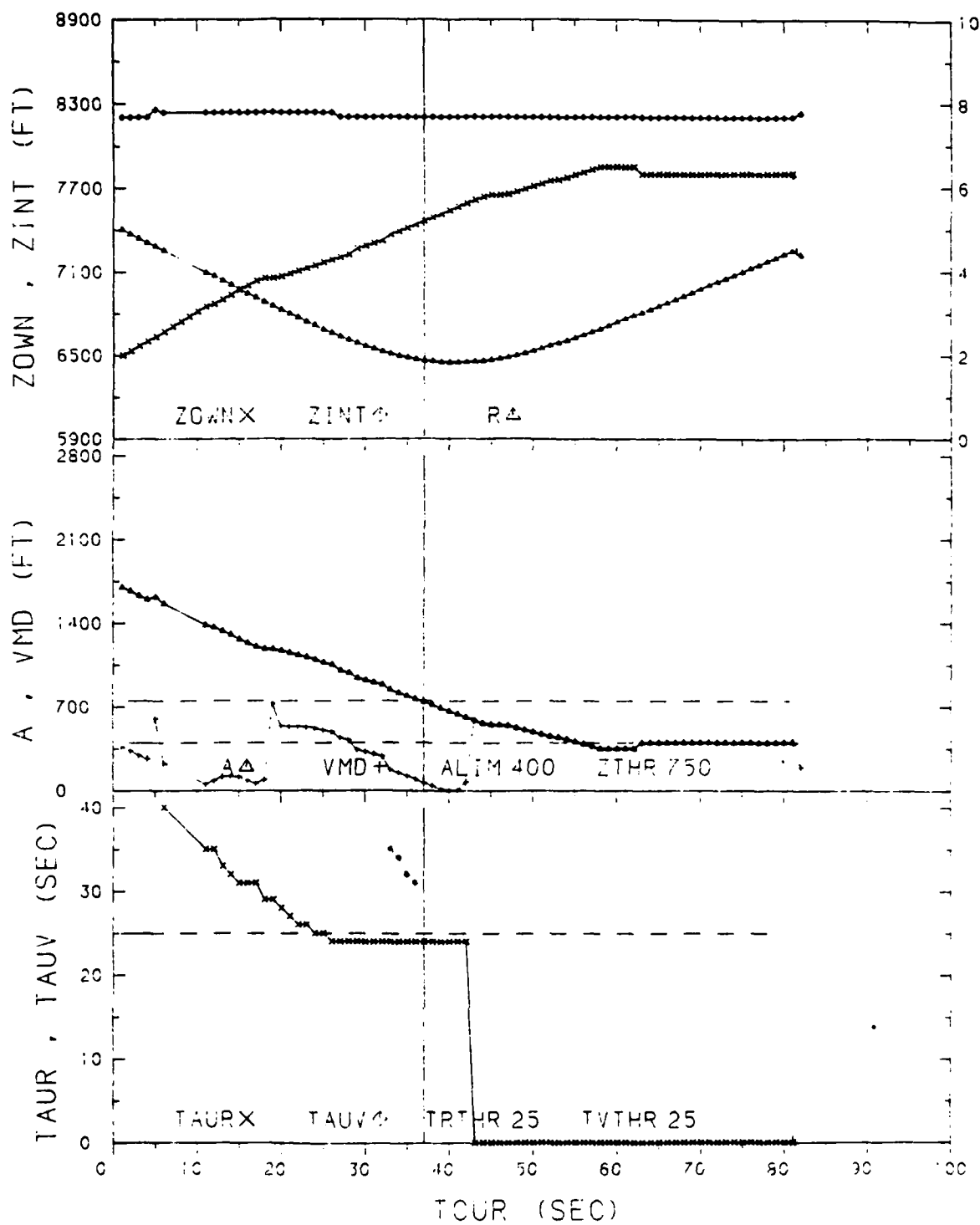


FIGURE D-16

TCAS WARNING 13: PARAMETERS

#### 14. TCAS WARNING 14

Piedmont Flight 105 departed Charlotte, North Carolina, on the night of April 20, 1987, en route to Greenville-Spartanburg, South Carolina. At approximately 0109Z, the aircraft was turning westbound 10 miles from Charlotte and climbing to 5,000 feet when the crew visually acquired traffic at 1 o'clock. ATC advised Flight 105 of the traffic shortly after visual acquisition and informed the crew that it was a B-737 on extended downwind for runway 36L, level at 6,000 feet. TCAS issued a Caution showing the intruder at 12 o'clock, 1100 feet above, and level while Flight 105 was still climbing. Flight 105 overshot its assigned 5,000-foot altitude by approximately 300 feet and, as the pilot began a descent back towards 5,000 feet, TCAS issued a LIMIT VERTICAL RATE - DO NOT CLIMB Warning. At this time the intruder was at approximately 2 1/2 miles, 11 o'clock, 700 feet above, and level. Flight 105 leveled at 5,000 feet and the Warning cleared with the intruder 1,000 feet above and at 8 o'clock. The flight conditions at the time were night, VMC, with visibility greater than 15 miles.

The observer notes on this encounter are shown in Figure D-17.

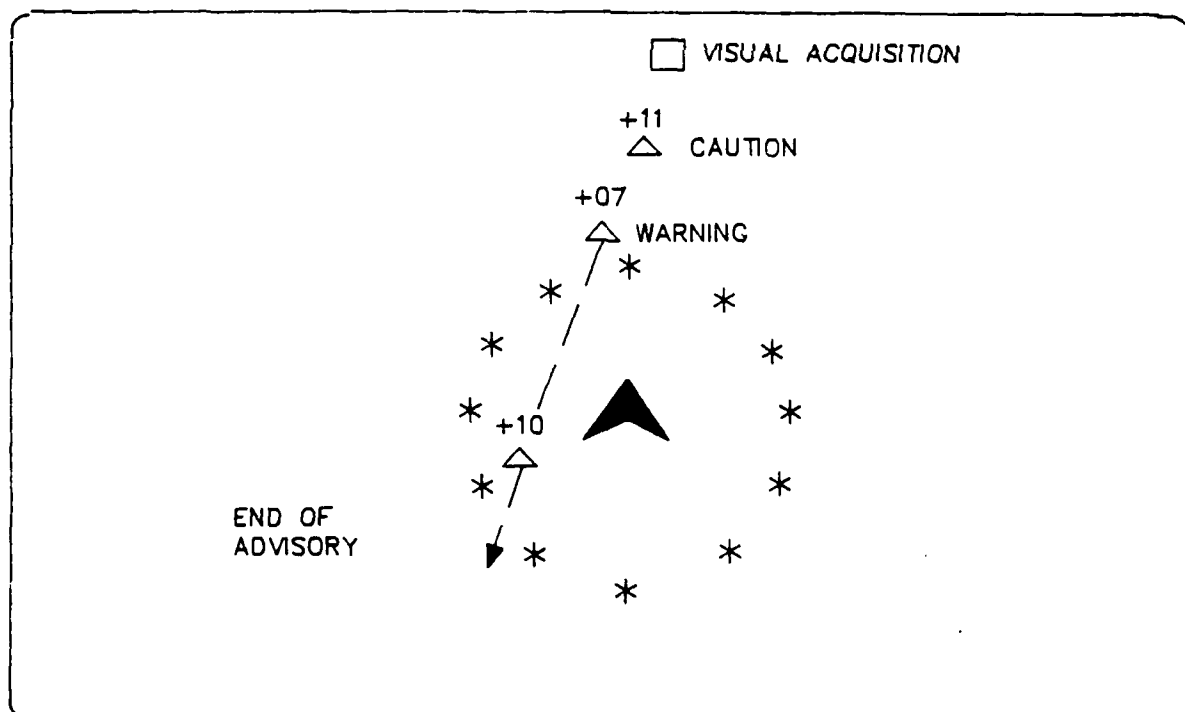
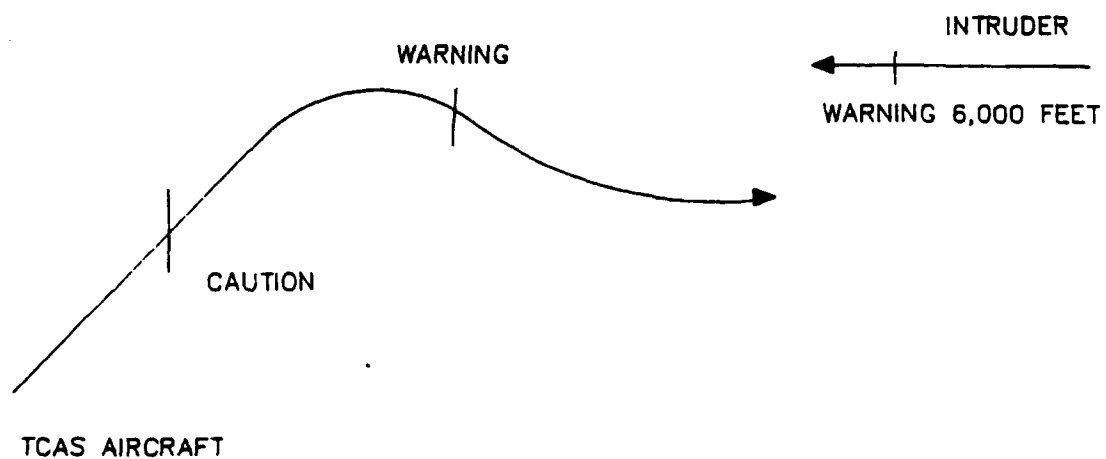


FIGURE D-17  
TCAS WARNING 14



15. TCAS WARNING 15

TCAS Warning 15 occurred when there was no observer on board the TCAS aircraft but while the TCAS avionics were operating in STANDBY. The recorded data for this encounter are shown in Figures D-18 and D-19.

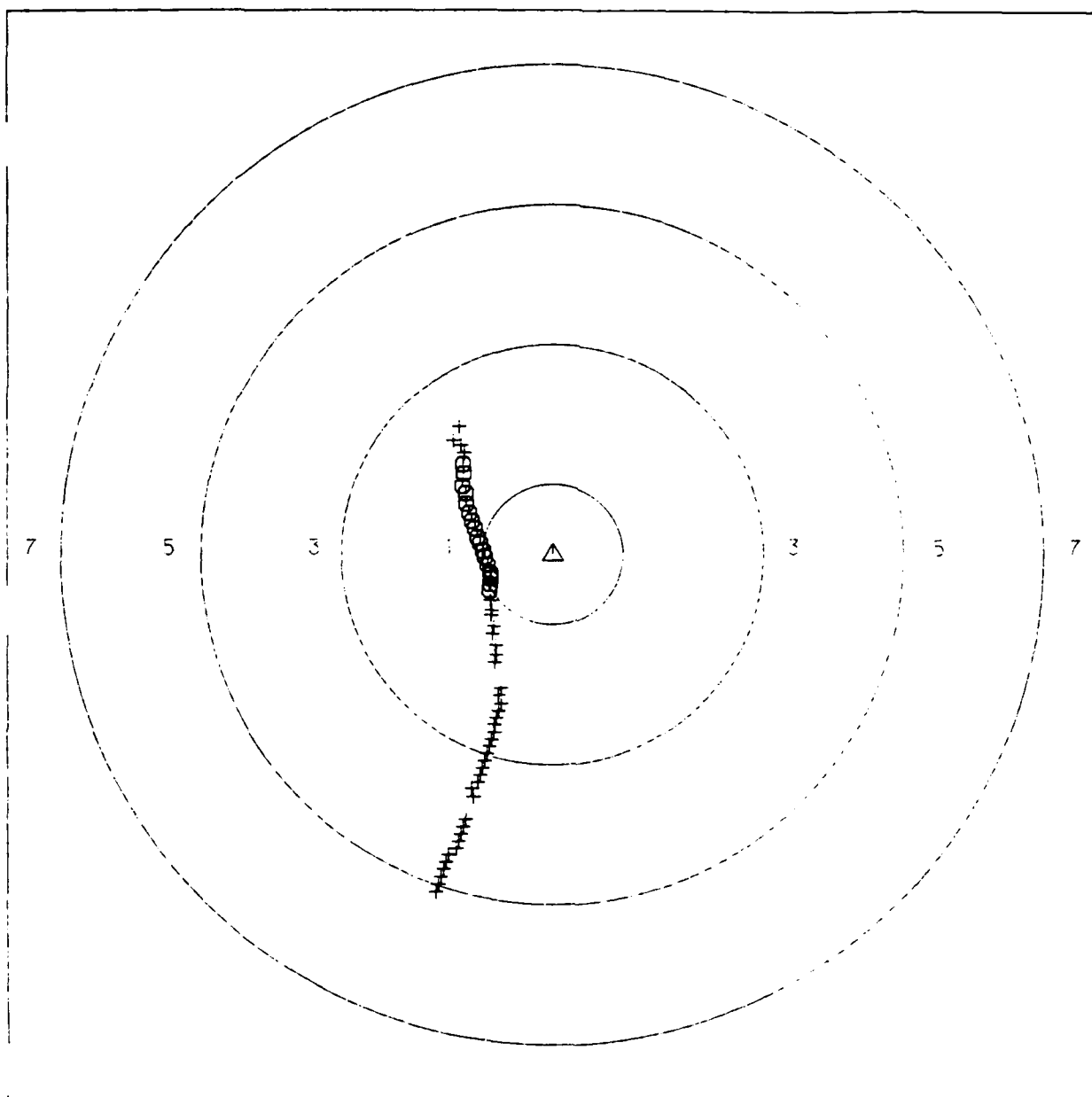


FIGURE D-18

TCAS WARNING 15: BEARING PLOT

FLIGHT RA    
 MC SIM RA

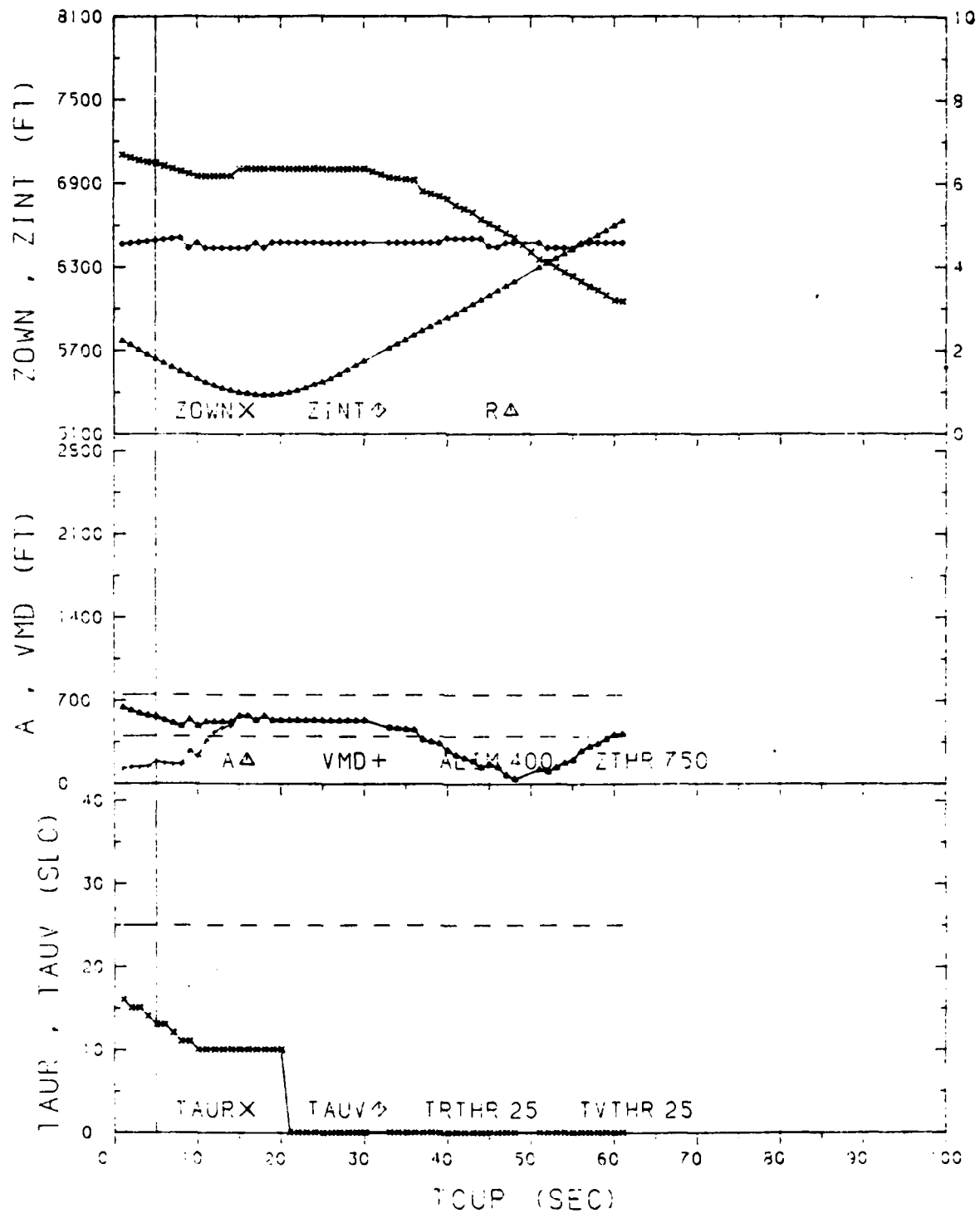


FIGURE D-19

TCAS WARNING 15: PARAMETERS

## 16. TCAS WARNING 16

On June 15, 1987, the TCAS aircraft was operating as Piedmont Flight 164 en route from Orlando, Florida, to Charlotte, North Carolina. At 1950Z the aircraft was established on a 7-mile final for runway 23 when TCAS generated a Caution showing traffic at 10 o'clock, 1,700 feet below and climbing, and at a range of approximately 5 miles. When the intruder was at 10 o'clock, 900 feet below, and at a range of 2 miles, the pilot flying Flight 164 leveled the aircraft at 5,000 feet. As the intruder closed within 2 miles, TCAS generated a warning to LIMIT VERTICAL RATE - DO NOT CLIMB and then changed to DESCEND, which placed Flight 164 in an altitude crossing situation. Although flight conditions were day, VMC, with visibility greater than 10 miles, the crew did not visually acquire the intruder. The intruder aircraft had leveled at 1,000 feet below Flight 164, and the TCAS aircraft crew asked ATC if it had traffic in this vicinity. ATC responded that it had previously alerted Flight 164 to the traffic.

Figure D-20 shows the data provided by the observer. The TCAS recorder did not provide data for this encounter.



## 17. TCAS WARNING 17

On June 16, 1987, the TCAS aircraft was operating as Piedmont Flight 163 en route from Washington, D.C., to Raleigh-Durham, North Carolina. At 1920Z the aircraft was northeast of its destination on the RDU 030 degree radial at approximately 21 DME. The aircraft was descending through 6,500 feet when ATC advised it of traffic and issued a vector (turn) for separation. Because of thunderstorms in the area, the crew was unable to accept the vector and was then instructed to maintain 7,000 feet because of converging traffic at 6,000 feet. The crew zoom-climbed to approximately 7,300 feet and had begun a descent back to 7,000 feet when the TCAS Caution was generated showing the intruder at 12 o'clock and level 1,200 feet below the TCAS aircraft. Flight 163 was completing a 1,200 fpm descent to 7,000 feet when a Warning was issued advising the crew to LIMIT VERTICAL RATE - DO NOT DESCEND GREATER THAN 2,000 FPM. At this time the intruder was 1,000 feet below, at a range of 2 miles, and 11 o'clock. The aircraft was just completing its descent, so no further action was required. The Warning cleared with the intruder 1,000 feet below Flight 163 and at the 8 o'clock position. Flight conditions at the time were day, marginal VMC, and visibility 3 miles in rain showers. There were also numerous buildups in the area that inhibited lateral maneuvering.

The recorded data for this encounter are shown in Figures D-21 and D-22.

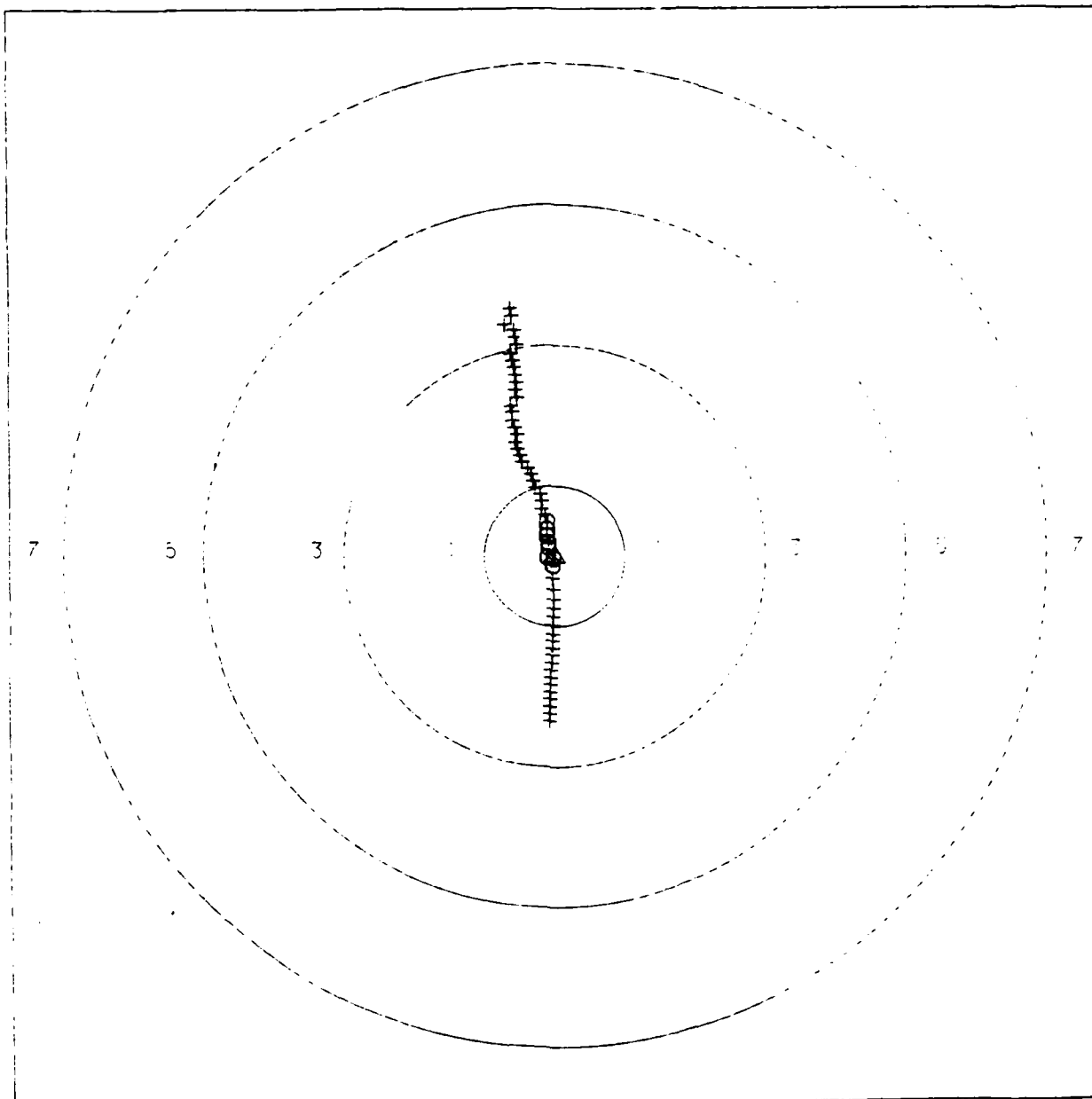


FIGURE D-21

TCAS WARNING 17: BEARING PLOT

FLIGHT RA  
MC SIM RA

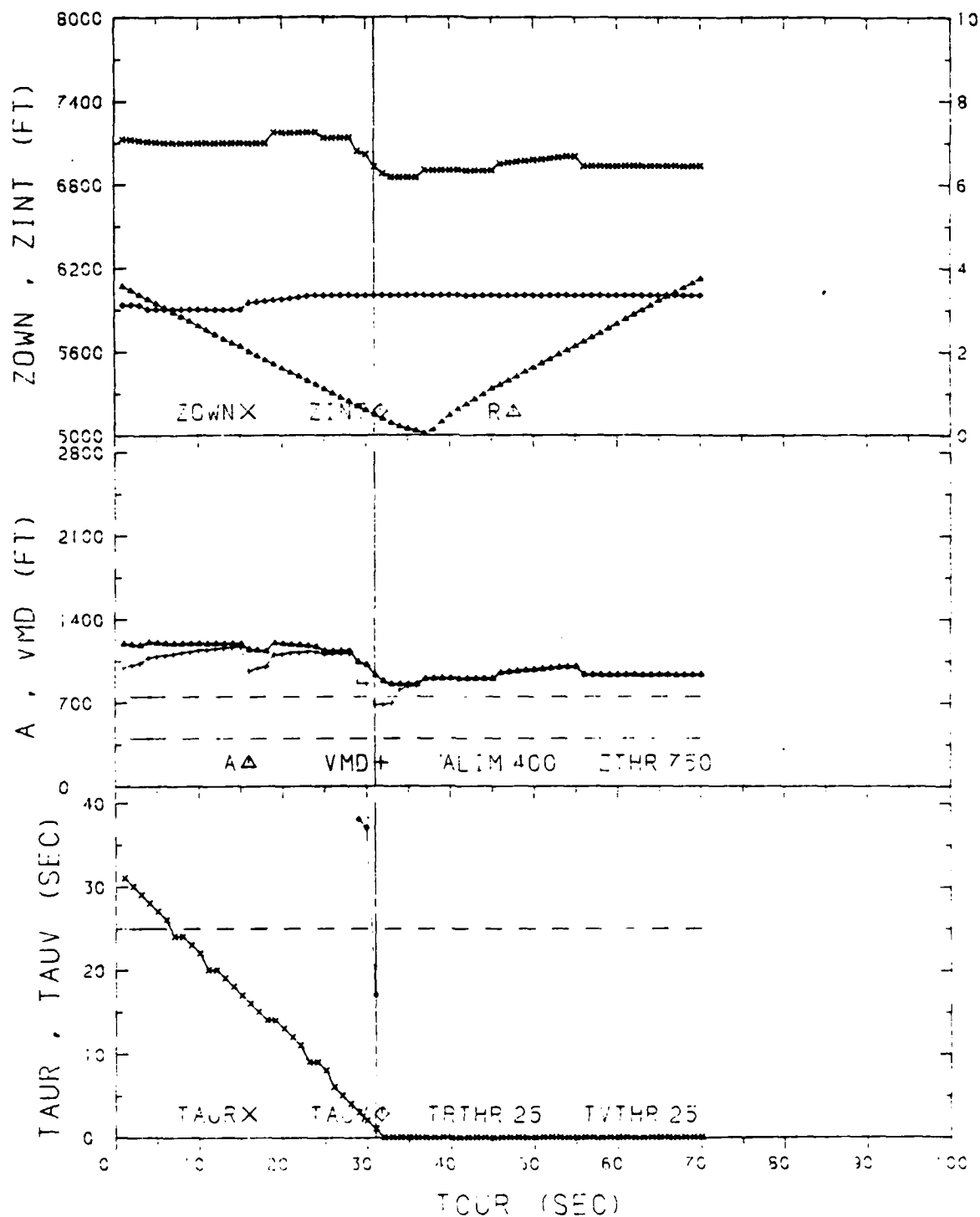


FIGURE D-22

TCAS WARNING 17: PARAMETERS



## 18. TCAS WARNING 18

TCAS Warning 18 was issued on a pop-up target and was not preceded by a Caution. On June 18, 1987, Piedmont Flight 79 departed Norfolk, Virginia, en route to Charlotte, North Carolina. Approximately 4 minutes from the airport, at 1448Z, the aircraft, passing over Chambers Field, was cleared to climb from its assigned altitude of 3,000 feet to 4,000 feet. At the same time, ATC cleared a Navy C-12 aircraft, which had taken off from Navy Norfolk (Chambers Field) to climb from 2,000 to 3,000 feet. As Flight 79 commenced its climb, a Warning was issued advising the crew to LIMIT VERTICAL RATE - DO NOT DESCEND GREATER THAN 500 FPM. The CRT display showed the intruder at 12 o'clock, at a range of 2 miles, 1,500 feet below, and climbing. No crew response was necessary, since the aircraft was establishing a positive rate of climb.

Analysis of the data shows that the intruder's initial rate of climb was determined to be extremely high. After the climb rate was re-initialized by TCAS, a more realistic vertical rate was established and the encounter was cleared. This was a preventive Warning that was issued: (1) because the vertical rate of the intruder was initially high and (2) because the system cannot establish intentions and did not know if the present climb of Flight 79 was going to be continued.

The recorded data for this encounter are shown in Figures D-23 and D-24.

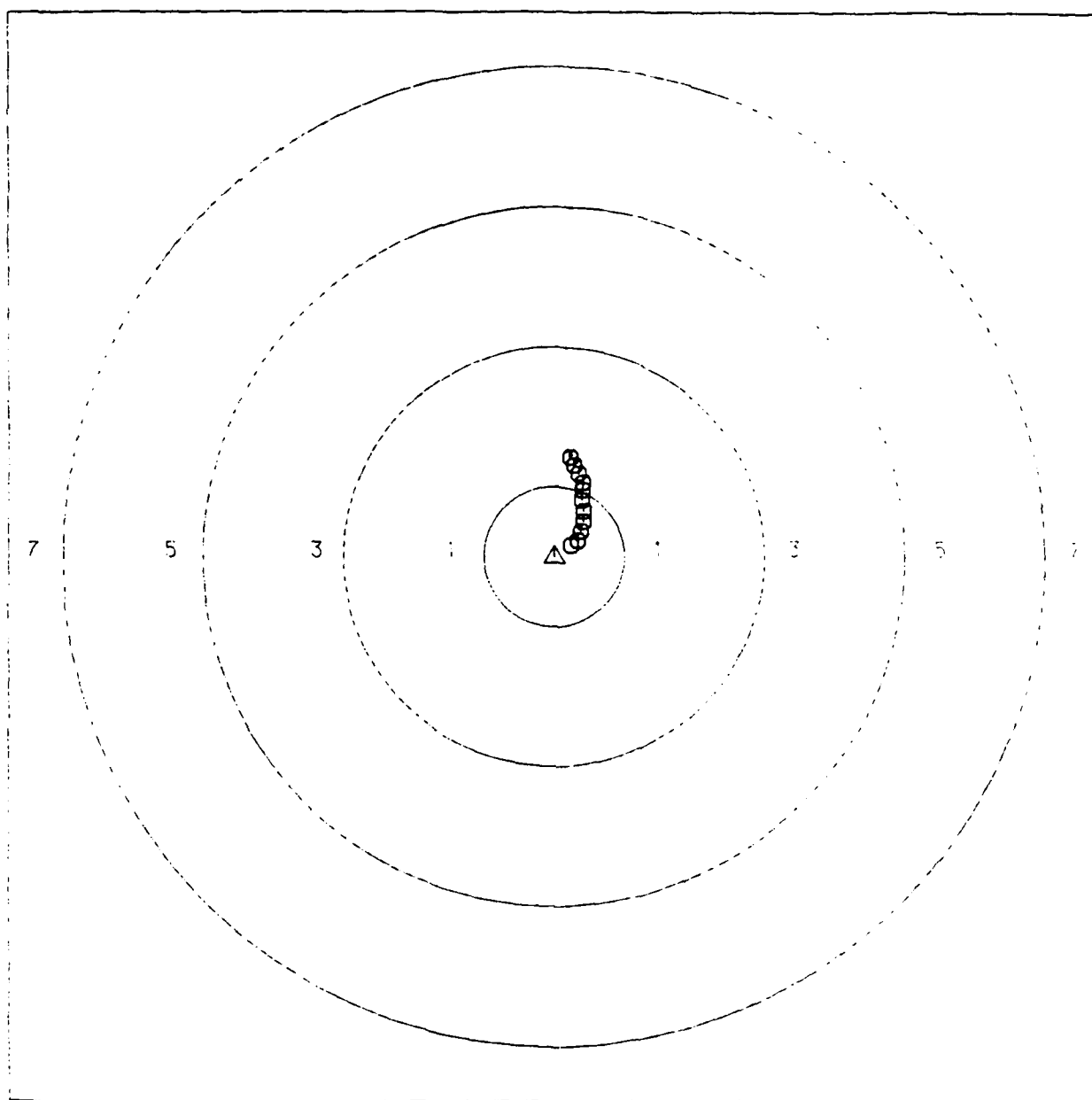
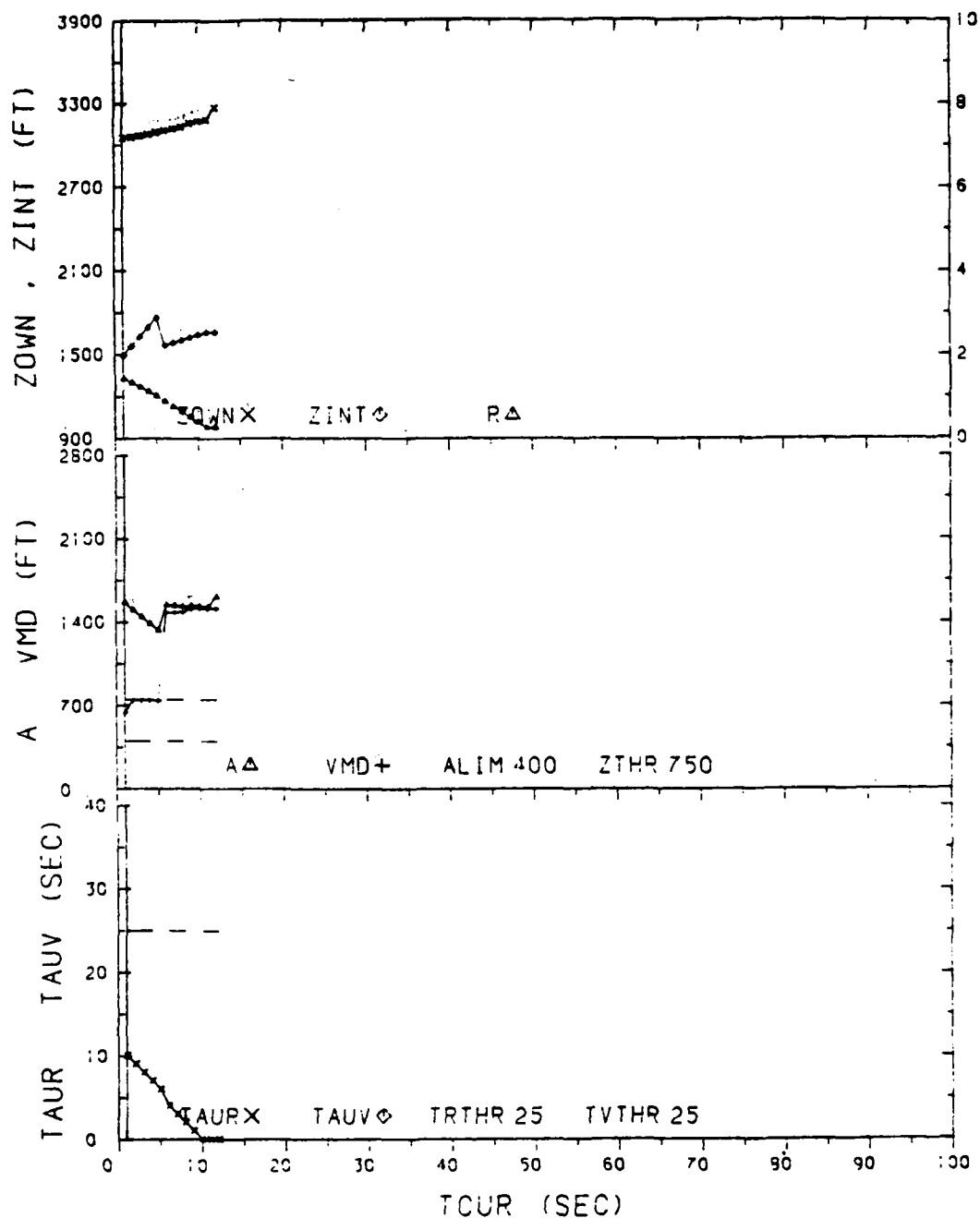


FIGURE D-23

TCAS WARNING 18: BEARING PLOT

FLIGHT RA

MC SIM RA



RA 86110624 ENCOUNTER NO. 23

START: 0 0: 0: 0 STOP: 0: 0: 0

FIGURE D-24

TCAS WARNING 18: PARAMETERS

#### 19. TCAS WARNING 19

Warning 19 was not witnessed by a TCAS observer. The recorded data for this encounter are shown in Figures D-25 and D-26. This encounter occurred on June 23, 1987, while the TCAS aircraft was operating on Flight 66 between Orlando, Florida, and Baltimore, Maryland.

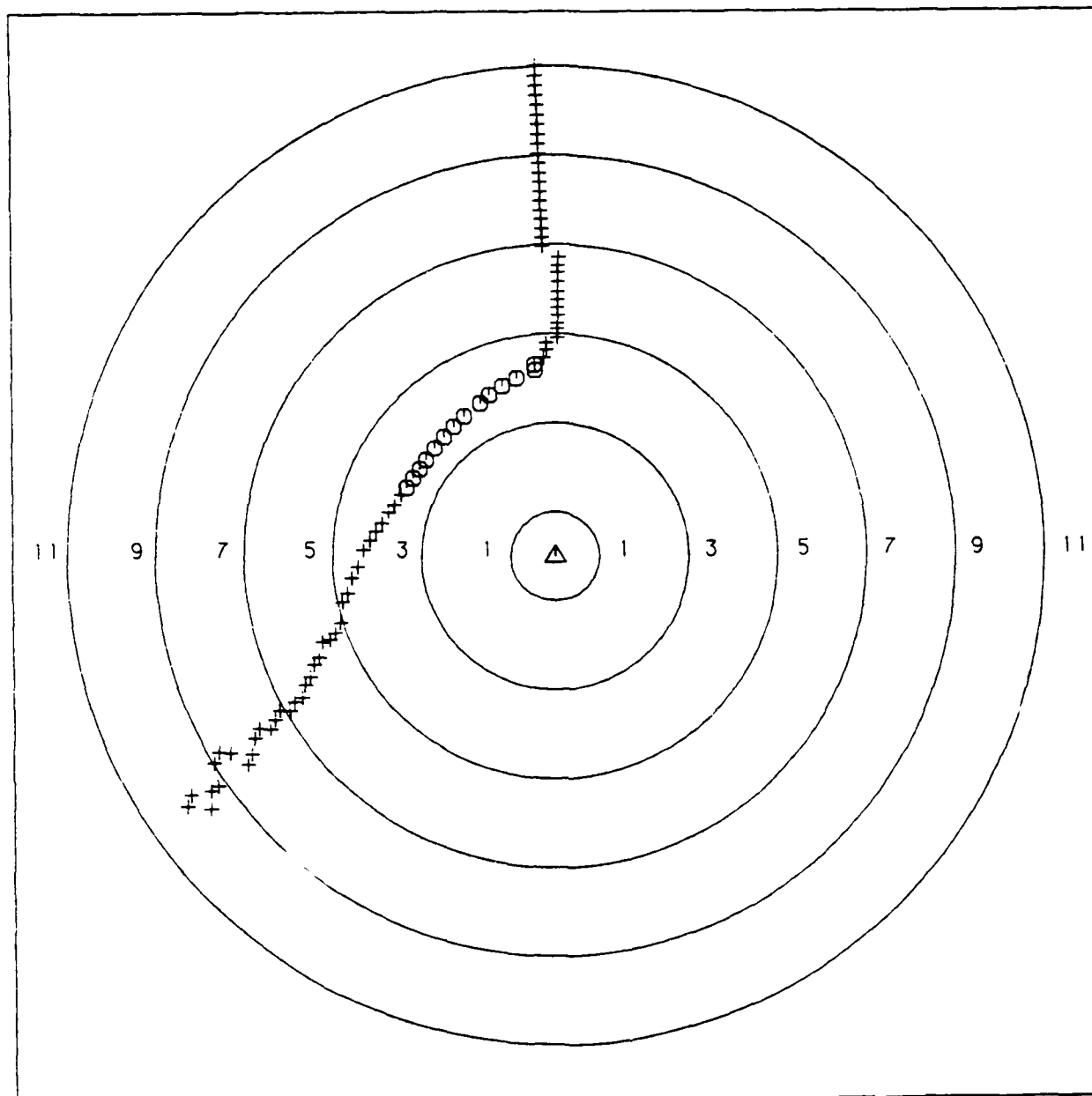



FIGURE D-25

TCAS WARNING 19: BEARING PLOT

FLIGHT RA   
 MC SIM RA

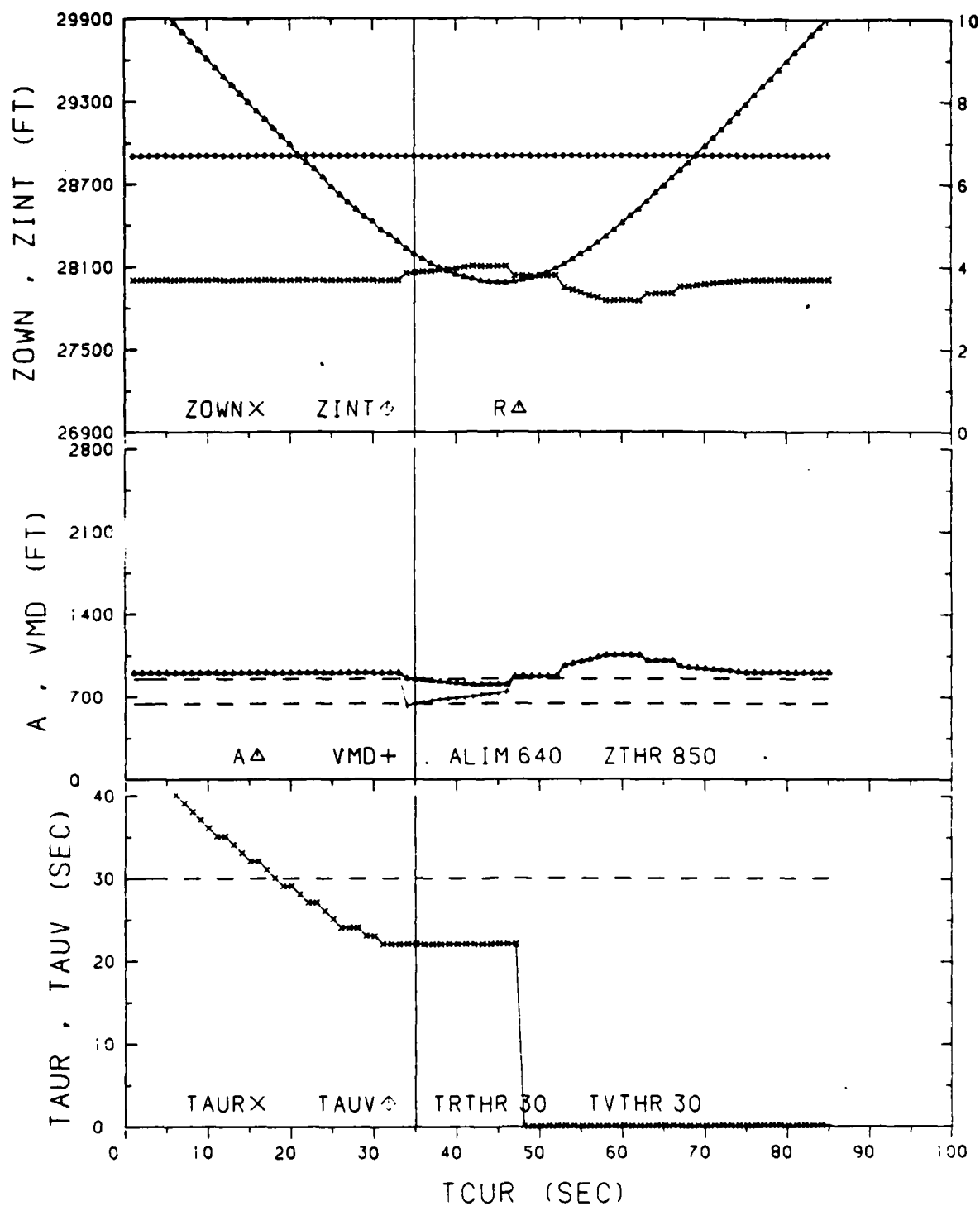


FIGURE D-26

TCAS WARNING 19: PARAMETERS

## TCAS WARNING 20

On June 19, 1987, the TCAS aircraft was operating as Piedmont Flight en route from Orlando, Florida, to Charlotte, North Carolina. The aircraft was approximately 25 miles southwest of Charlotte and was ascending to its cleared altitude of 10,000 feet. Flight conditions were day, VMC, with visibility approximately 4 miles. At 1740Z, Charlotte approach control advised Flight 72 of conflicting traffic at 1 o'clock, 1,000 feet below, and level. As the crew initiated a visual search, TCAS generated a Caution on the same traffic and displayed it at 2 o'clock, 1,000 feet below, and level. Using the ATC advisory and TCAS, the crew acquired the traffic visually. As the TCAS aircraft approached 10,000 feet, ATC cleared it to maintain 4,000 feet and issued a 60 degree turn to avoid traffic. TCAS continued to show the intruder as a Caution until the altitude separation was 600 feet, at which time it issued a Warning to LIMIT VERTICAL RATE - DO NOT DESCEND. Since the crew had the intruder in sight and there was adequate lateral separation, the descent was continued. With the CRT showing an altitude difference of 500 feet, the Warning changed to CLIMB. The intruder passed below and to the left of Flight 72, and when it reached the 7 o'clock position, the encounter cleared. The observer noted that had ATC not vectored Flight 72 around the intruder, the TCAS advisories would have been proper and followed by the crew.

The observer's drawing of this encounter's geometry is shown in Figure D-27.

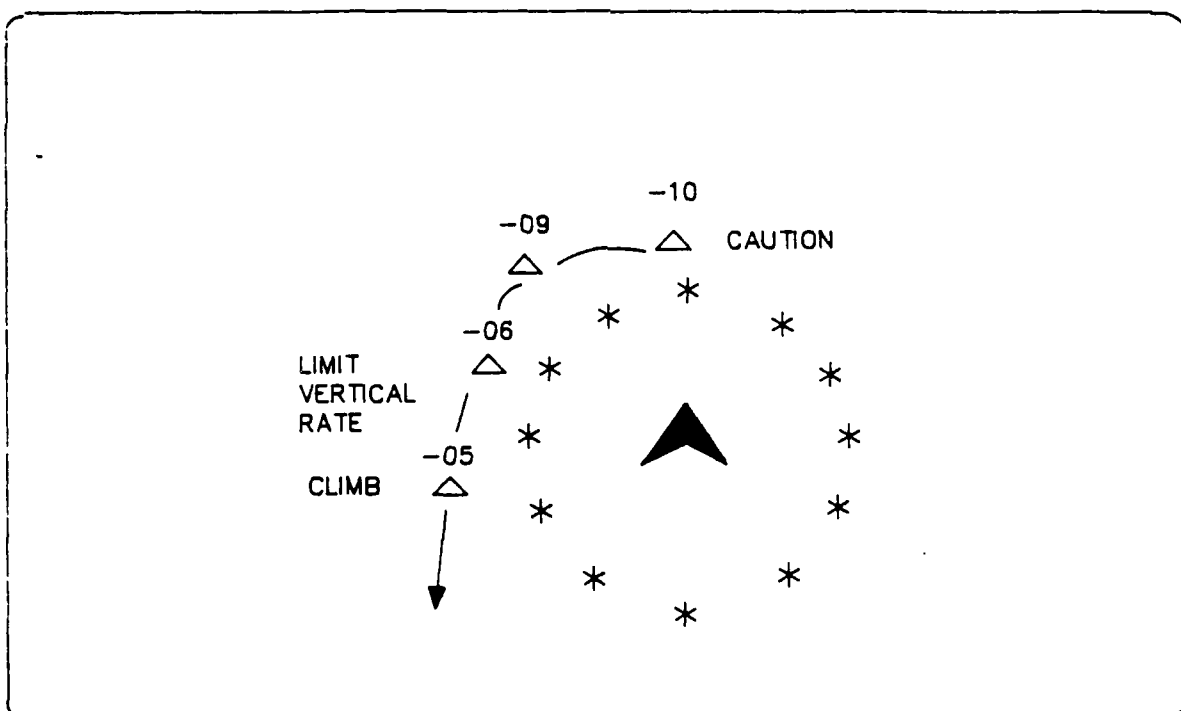
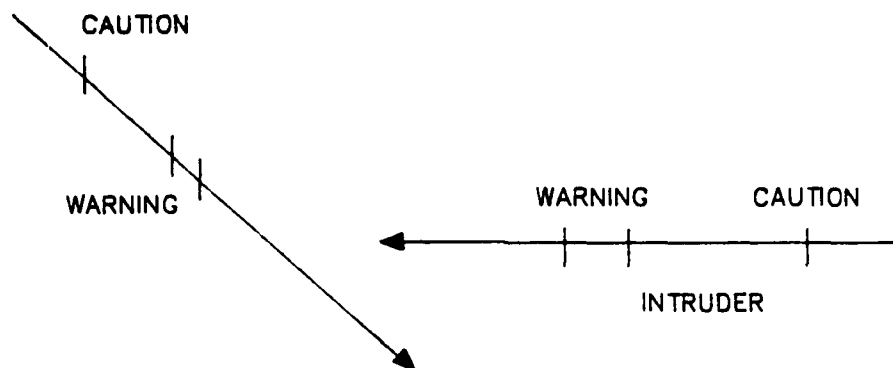


FIGURE D-27

TCAS WARNING 20



## 21. TCAS WARNING 21

Piedmont Flight 66 was scheduled to provide service between Baltimore, Maryland, and Boston, Massachusetts, on June 23, 1987. The aircraft had just departed BWI, and the crew was configuring the aircraft for climb while passing 3,000 feet for the assigned altitude of 9,000 feet. At 0140Z, TCAS generated a Caution showing the traffic at approximately 2 o'clock, 600 feet below, and climbing. The lateral separation was determined to be about 2 miles. The crew gained visual contact with the traffic, and Flight 72 continued its 1,100 fpm climb as it accelerated to climb speed. When the intruder reached the 3 o'clock position, TCAS issued a Warning to CLIMB. Since there was adequate lateral separation, the crew had the traffic in sight, and the intruder's climb rate was determined to be lower than that of Flight 66, the pilot did not consider it necessary to increase his climb rate and continued at 1,100 fpm. The encounter cleared as the intruder fell to the 4 o'clock position and the altitude difference increased to 700 feet. Flight conditions were night, VMC, with visibility 10 miles. no ATC traffic advisories were issued.

The recorded data for this encounter are shown in Figures D-28 and D-29.

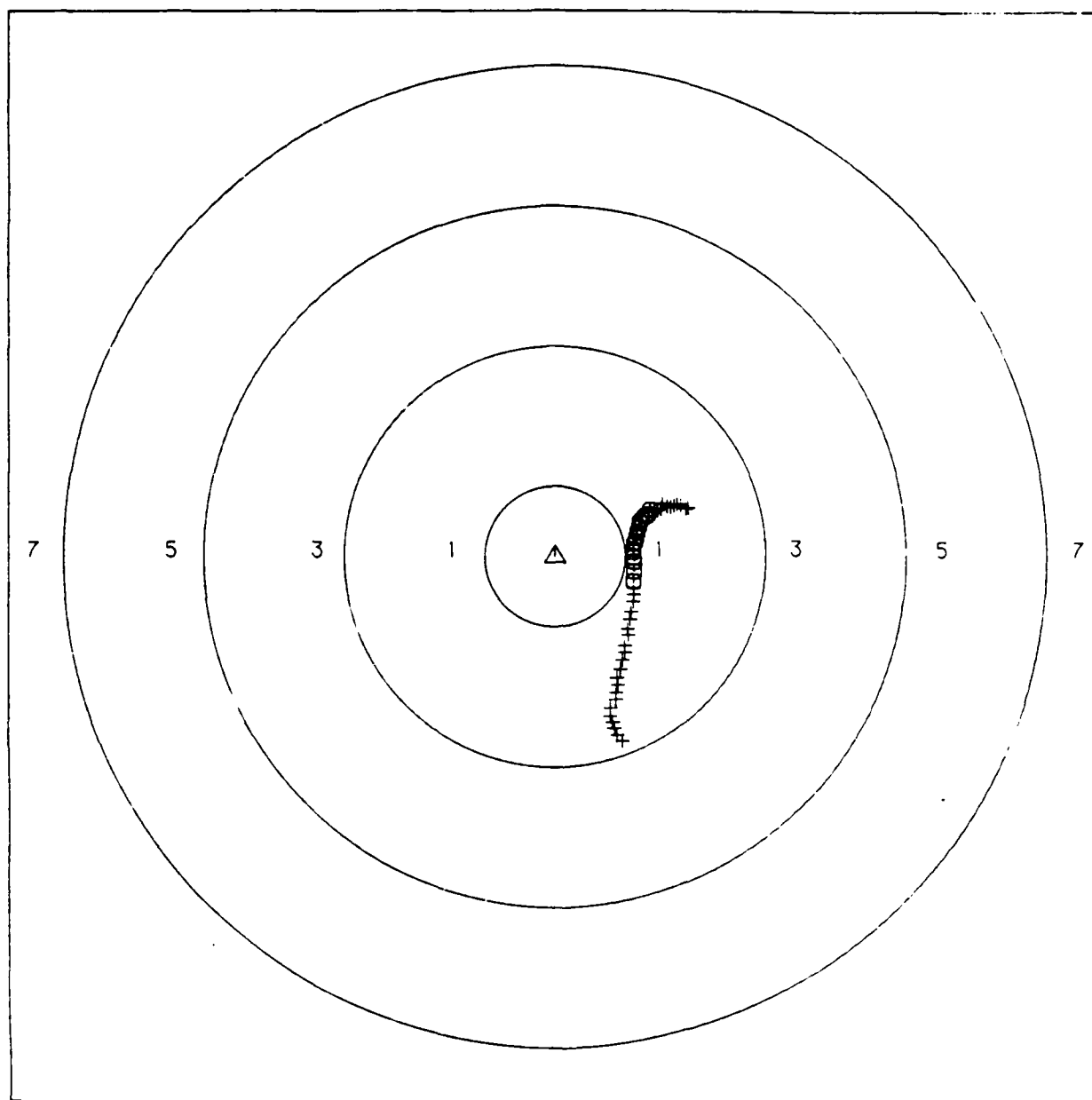


FIGURE D-28

TCAS WARNING 21: BEARING PLOT

FLIGHT RA .....  
 MC SIM RA .....

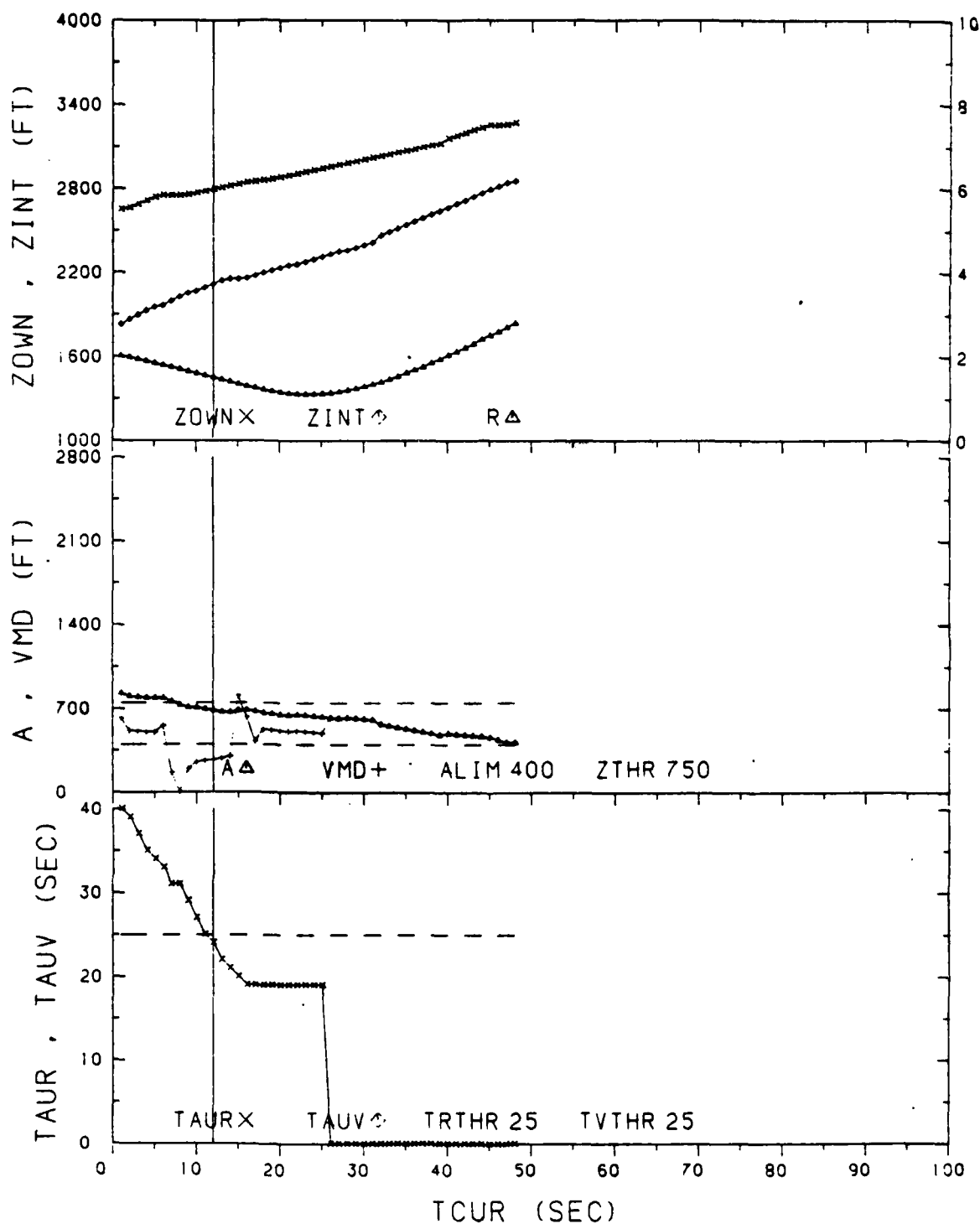


FIGURE D-29

TCAS WARNING 21: PARAMETERS

## 22. TCAS WARNING 22

On June 24, 1987, Piedmont Flight 37 was en route from Boston, Massachusetts, to Richmond, Virginia. At 2331Z, the aircraft was approximately 45 miles northeast of Richmond and descending through 12,000 feet when a TCAS Caution was generated. Flight conditions were day, VMC, with visibility greater than 10 miles. The Caution showed traffic at 11 o'clock, 2,900 feet below Flight 37, and level, with a range of approximately 3 miles. As the intruder symbol tracked down the left side of the aircraft, the altitude and range separation continued to decrease. A LIMIT VERTICAL RATE - DO NOT DESCEND GREATER THAN 2,000 FPM Warning was issued when the intruder was at 10 o'clock, 1,100 feet below, and at a range of approximately 1 mile. The pilot reduced the descent rate to approximately 1,500 fpm. Visual contact with the traffic was established, and it continued to track down the left side of Flight 37. At the 3 o'clock position the altitude separation was 600 feet with a range of approximately 1.5 miles. When the intruder reached the 7 o'clock position, the encounter cleared.

The data from this encounter are shown in Figures D-30 and D-31.

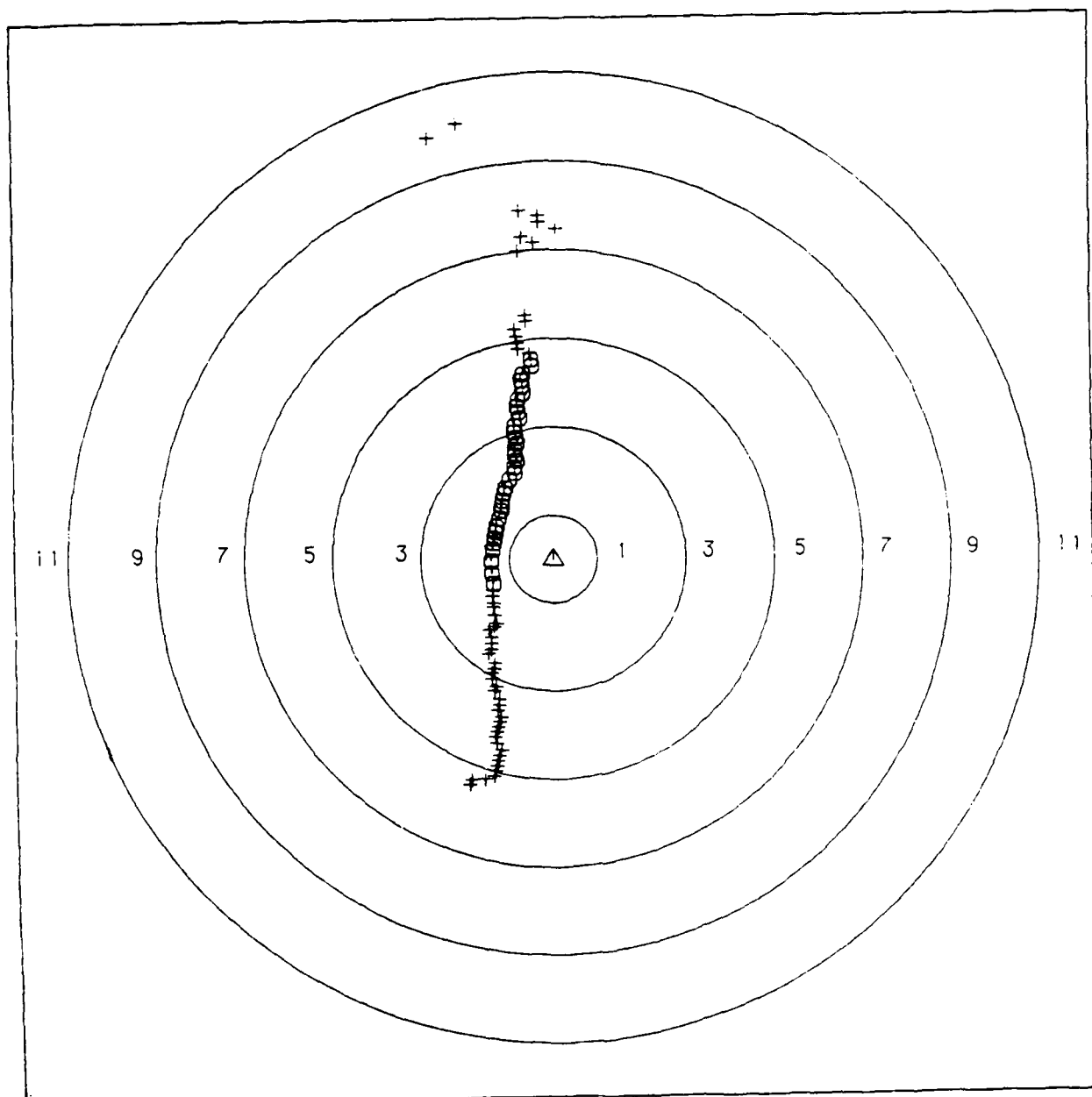


FIGURE D-30

TCAS WARNING 22: BEARING PLOT

FLIGHT RA  
MC SIM RA

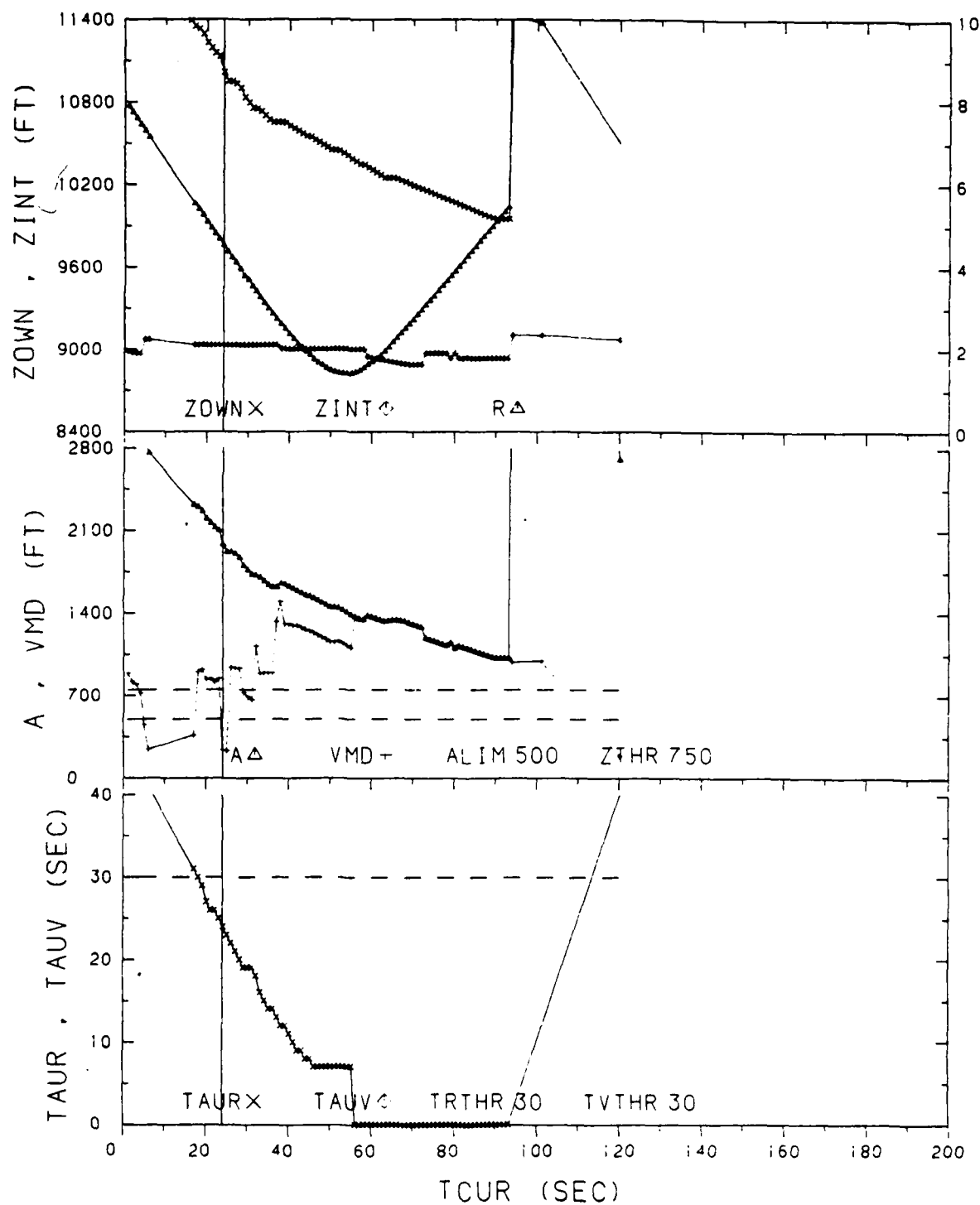


FIGURE D-31

TCAS WARNING 22: PARAMETERS

23. TCAS WARNING 23

TCAS Warning 23 was unobserved. The recorded data for this encounter are shown in Figures D-32 and D-33.

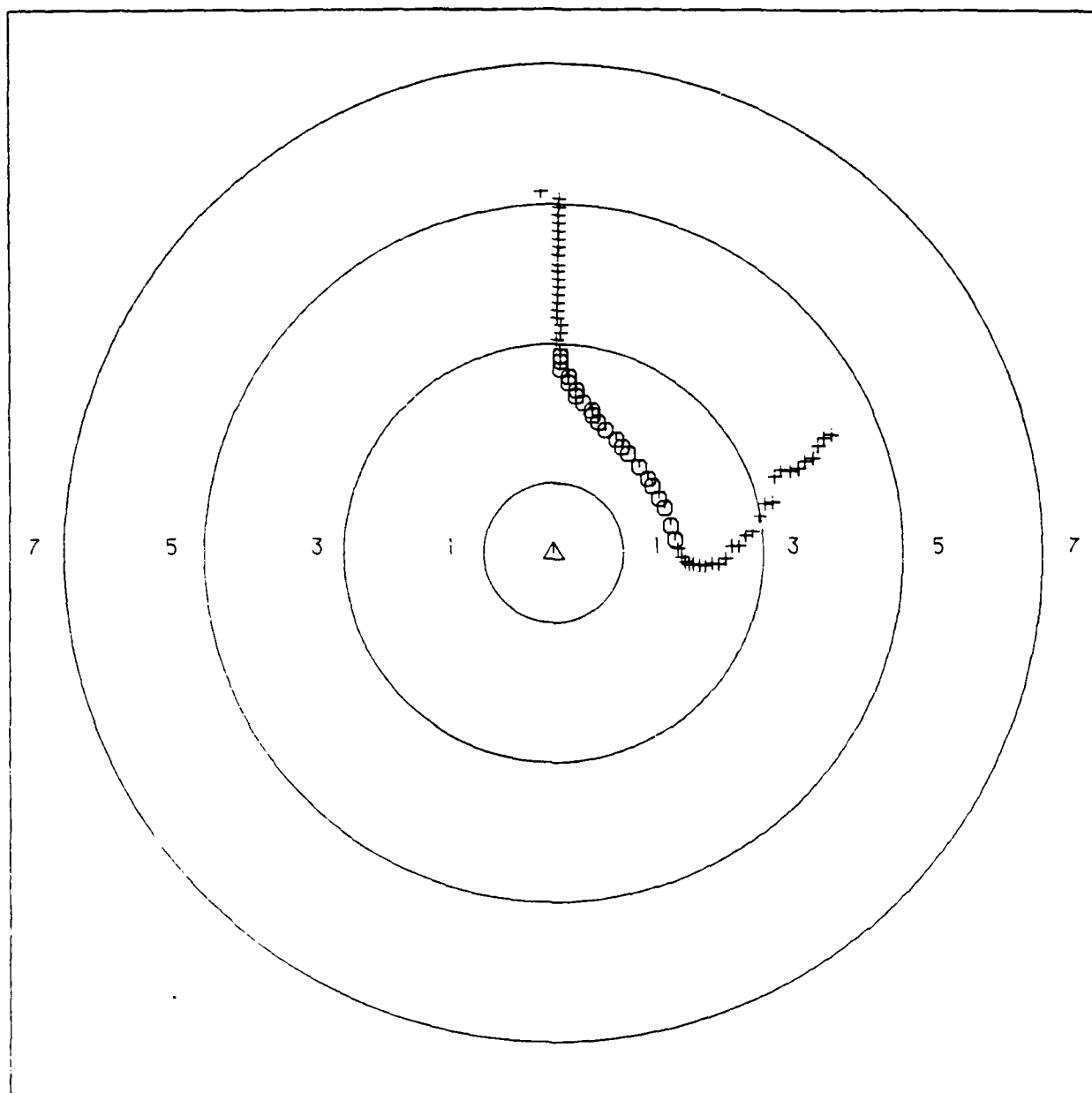


FIGURE D-32

TCAS WARNING 23: BEARING PLOT



FLIGHT RA -----  
 MC SIM RA -----

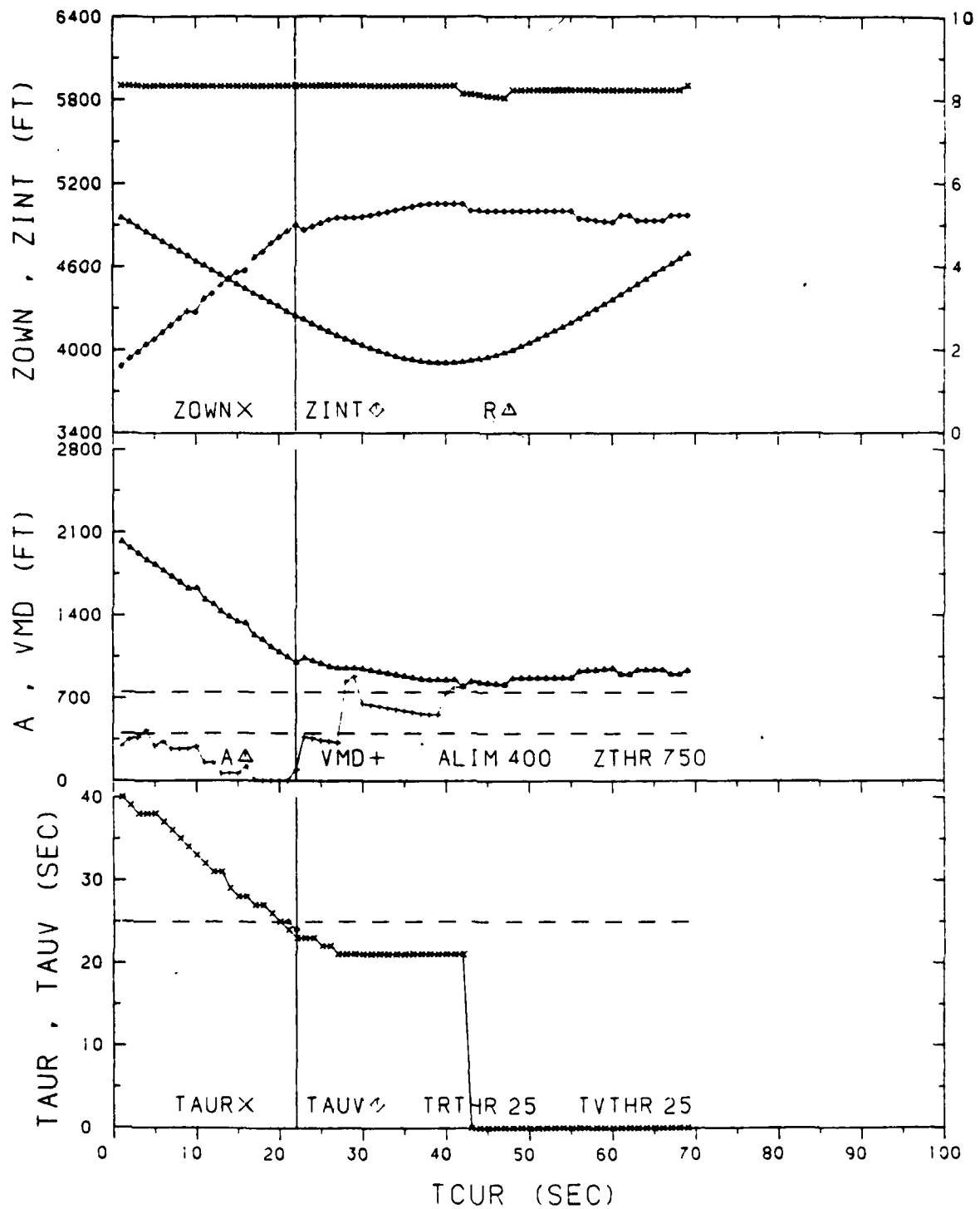


FIGURE D-33

TCAS WARNING 23: PARAMETERS

#### 24. TCAS WARNING 24

The TCAS aircraft was operating as Piedmont Flight 115 on June 28, 1987, providing service between Dayton, Ohio, and Grand Rapids, Michigan. At 1833Z, the aircraft was 15 miles south of Grand Rapids on the GRR 170 degree radial, descending through 9,000 feet to its assigned clearance of 3,000 feet when ATC issued a traffic advisory. The intruder aircraft was turning parallel to Flight 115, was below, and was at a range of approximately 3 miles. ATC instructed Flight 115 to maintain 9,000 feet until the traffic was in sight. Shortly after the ATC advisory, TCAS issued a Caution showing the traffic at 2 o'clock, 1,400 feet below and level, and at a range of 3.5 miles. The crew was able to visually acquire the intruder, at which time ATC cleared Flight 115 to continue its descent and maintain visual separation. The intruder symbol tracked in toward Flight 115 until the altitude difference was 700 feet and the horizontal separation was approximately 1 mile. At this point, TCAS issued a DO NOT DESCEND Warning, followed by a CLIMB Warning. Separation at the time of the CLIMB Warning was approximately 300 feet vertically and 1 mile laterally. Flight conditions at the time of the encounter were day, VMC, with visibility greater than 20 miles. Since the crew was able to maintain visual separation with the intruder, they felt comfortable in ignoring the warnings.

The recorded data for this encounter are shown in Figures D-34 and D-35.

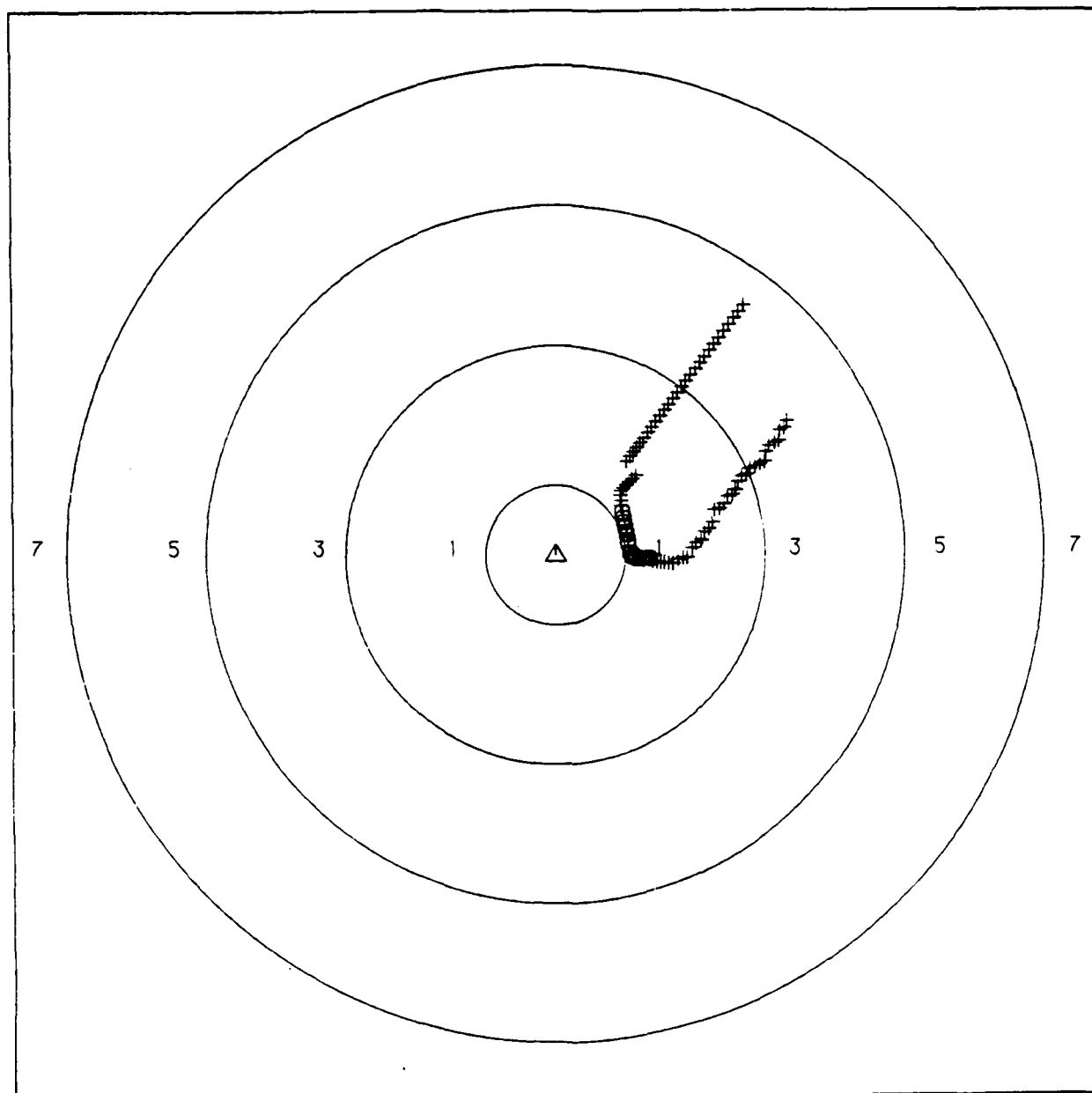


FIGURE D-34

TCAS WARNING 24: BEARING PLOT

FLIGHT RA ---  
 MC SIM RA

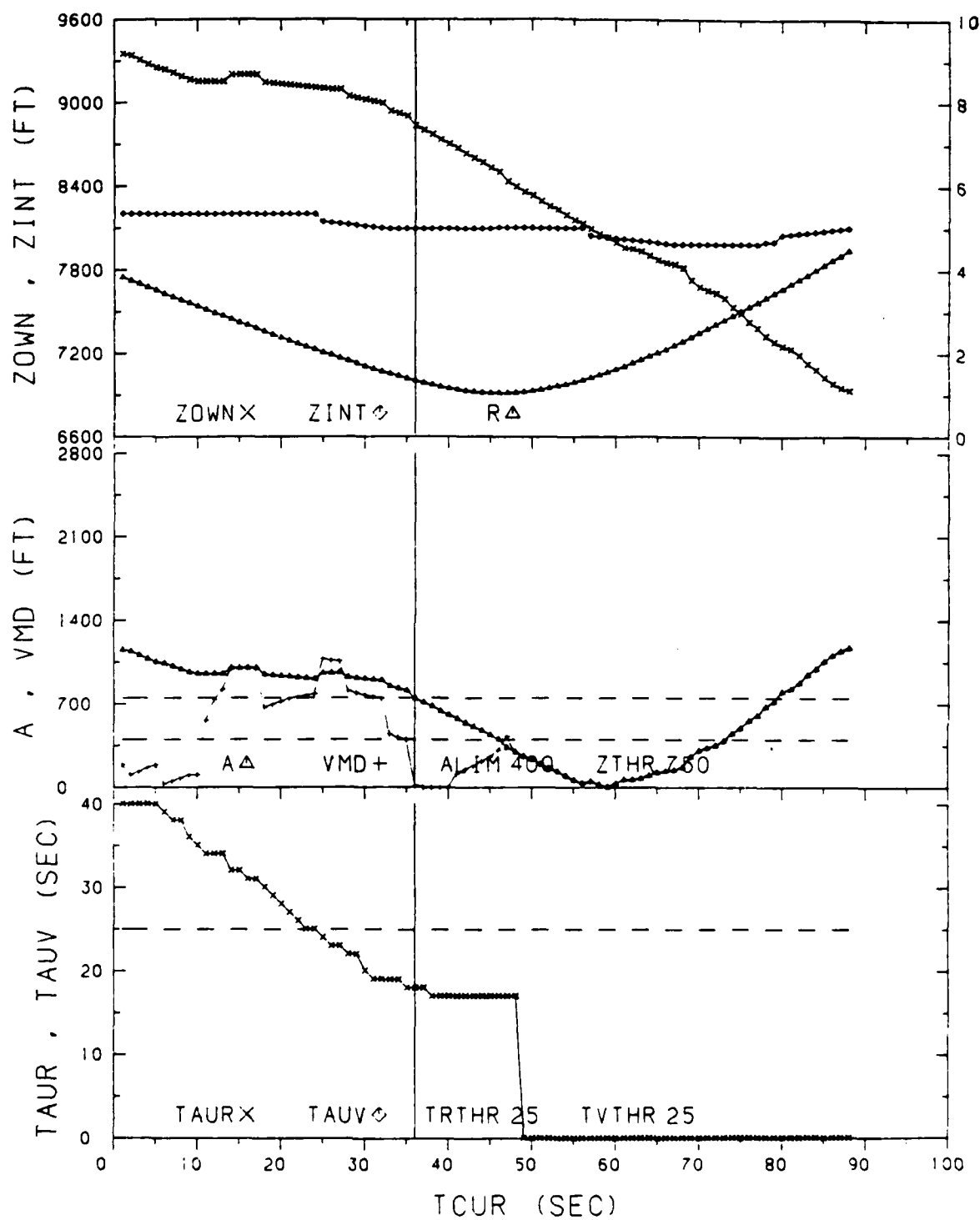


FIGURE D-35

TCAS WARNING 24: PARAMETERS

## 25. TCAS WARNING 25

On July 4, 1987, Piedmont Flight 79 was en route to Dallas - Ft. Worth, Texas, from Charlotte, North Carolina. The aircraft was maneuvering in the DFW terminal area on the downwind leg for a landing on runway 17L. Flight conditions were day, VMC, with visibility greater than 10 miles. At 1646Z, as the TCAS aircraft was descending through 7,000 feet, TCAS generated a Caution showing traffic at 10 o'clock, 1,600 feet below, and climbing. The crew visually acquired the traffic and was continuing to descend when a TCAS warning to LIMIT VERTICAL RATE - DO NOT DESCEND was issued. At this time the intruder was at 9 o'clock, 1,200 feet below and climbing, and at a range of 1 mile. The pilot flying the aircraft stopped the descent. ATC then issued Flight 79 a right turn to avoid the traffic. As the aircraft began its turn, the Warning was removed. ATC did not make specific mention of the traffic but did advise Flight 79 that the right turn was for traffic separation.

The observer's notes for this encounter are shown in Figure D-36. No TCAS data were recorded during this encounter.

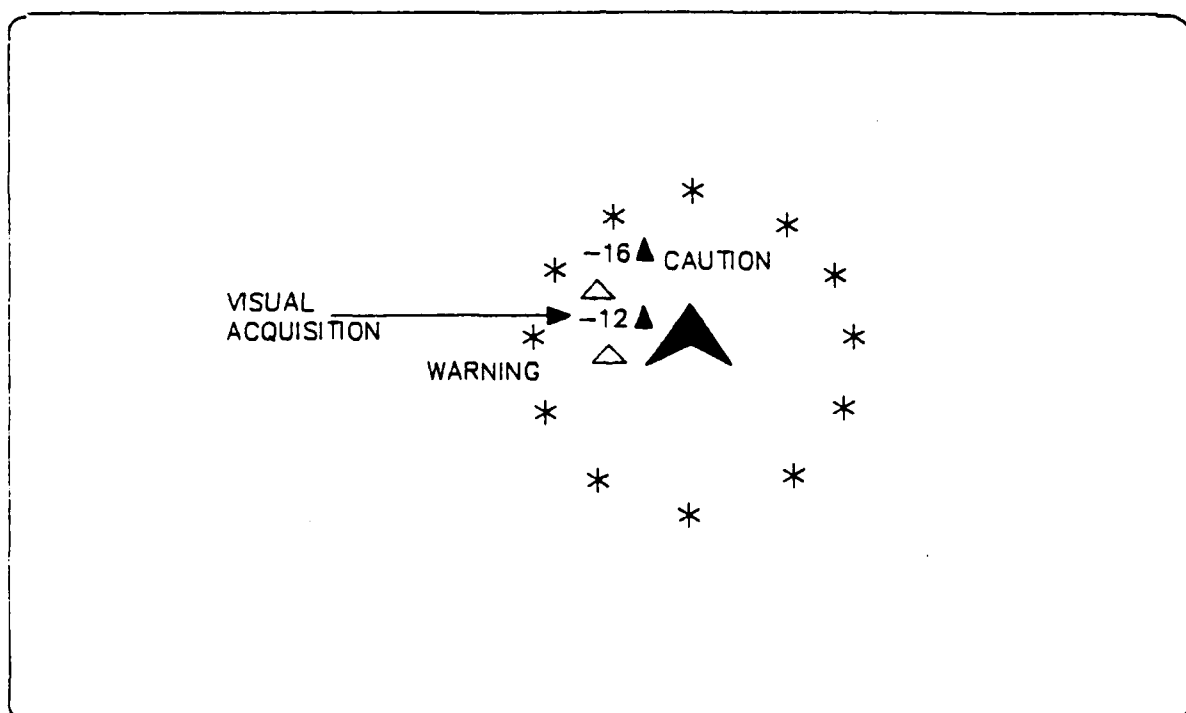
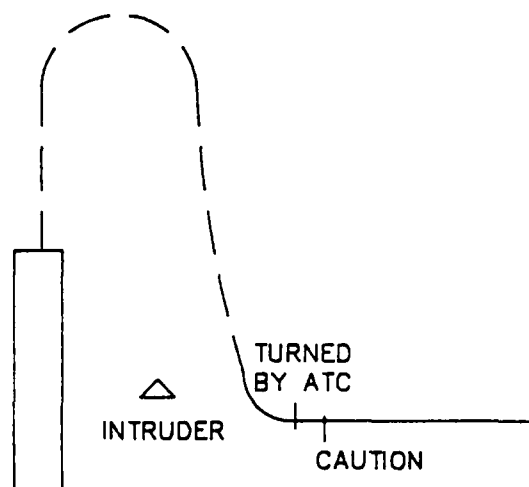


FIGURE D-36  
TCAS WARNING 25

26. TCAS WARNING 26

Warning 26 occurred while there was no observer on board the TCAS aircraft. The recorded data for this encounter are shown in Figures D-37 and D-38.

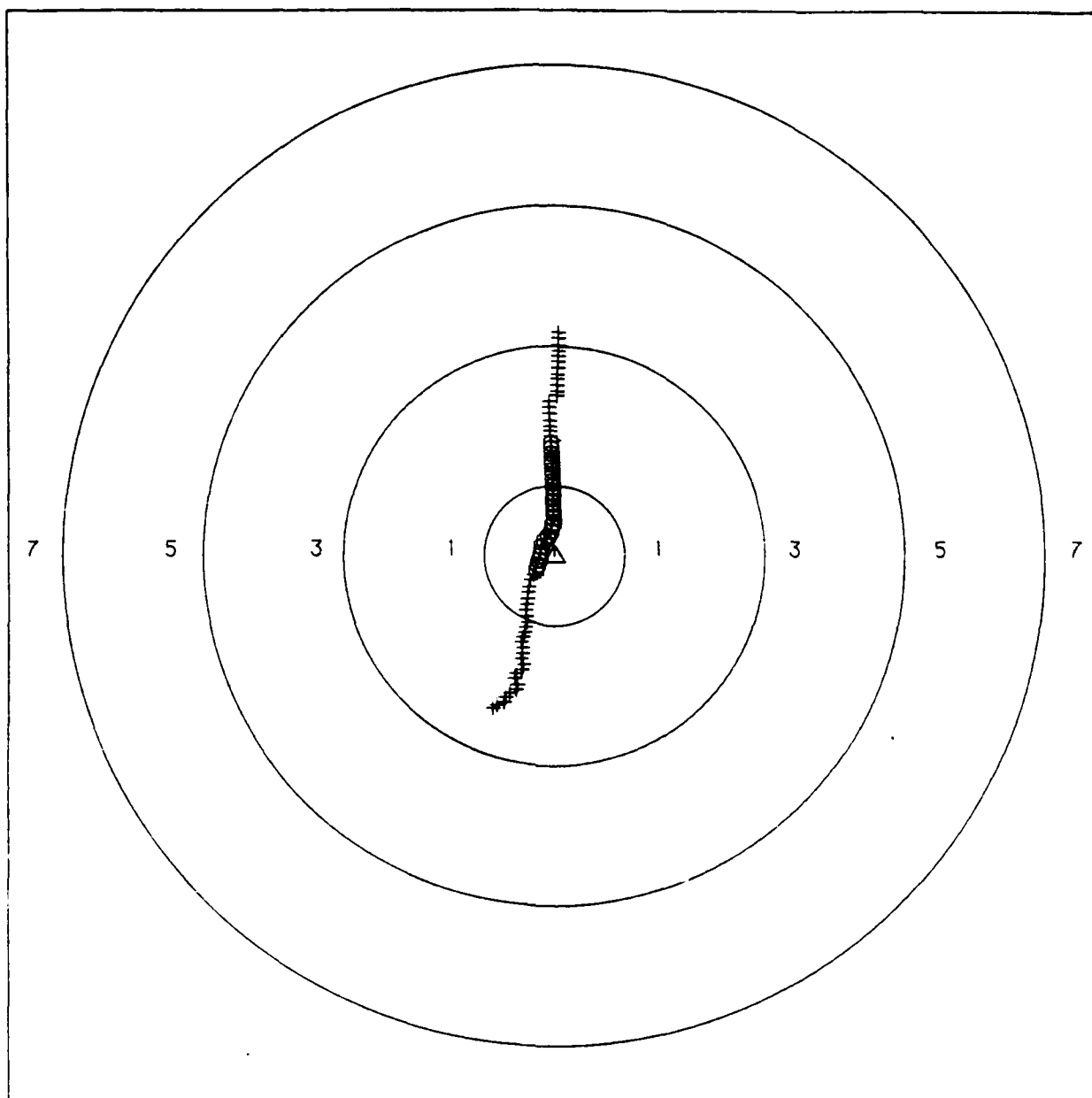


FIGURE D-37

TCAS WARNING 26: BEARING PLOT



FLIGHT RA .....  
 MC SIM RA .....

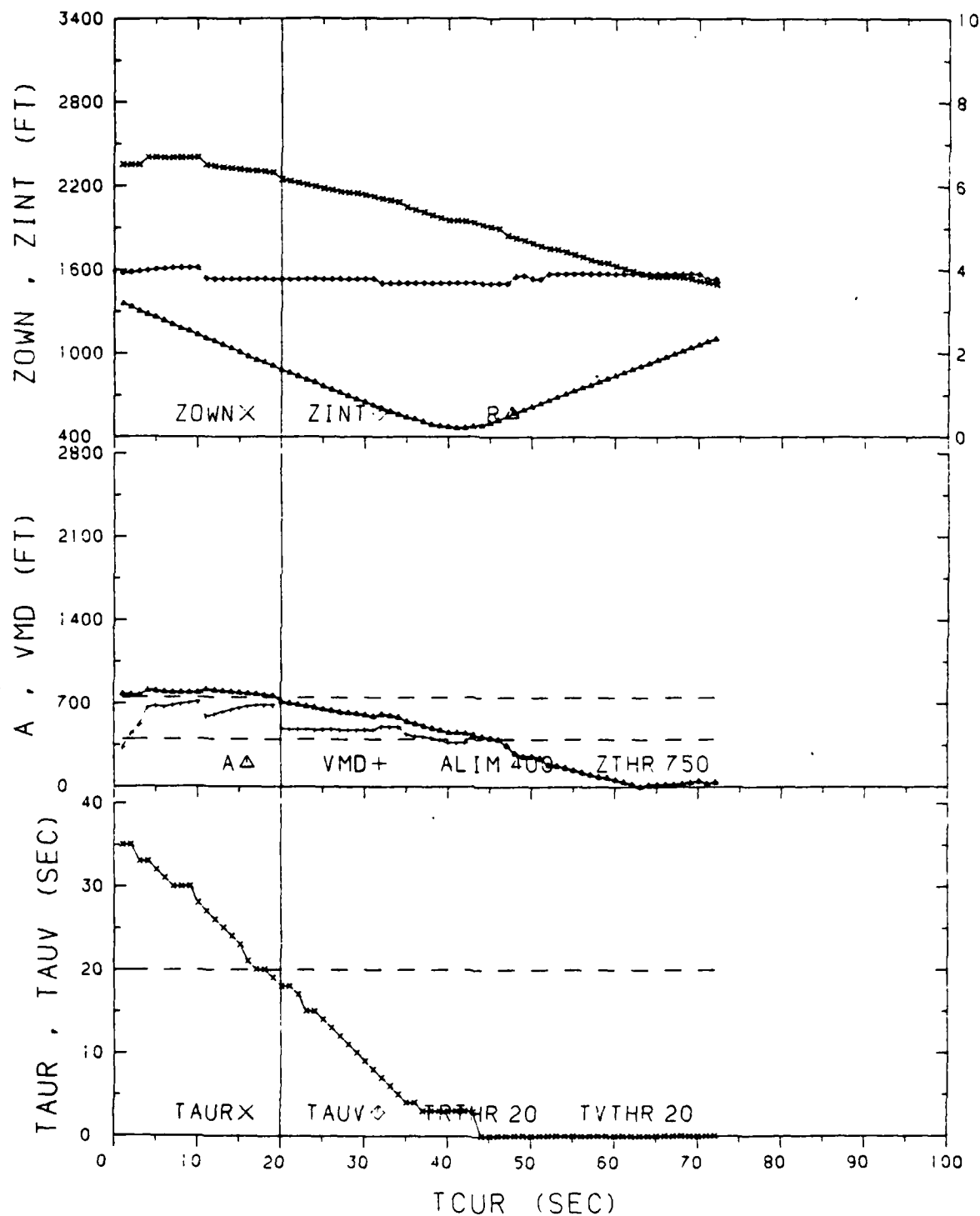


FIGURE D-38

TCAS WARNING 26: PARAMETERS

## 27. TCAS WARNING 27

Warning 27 occurred while there was no observer on board the TCAS aircraft. The recorded data for this encounter are shown in Figures D-39 and D-40.

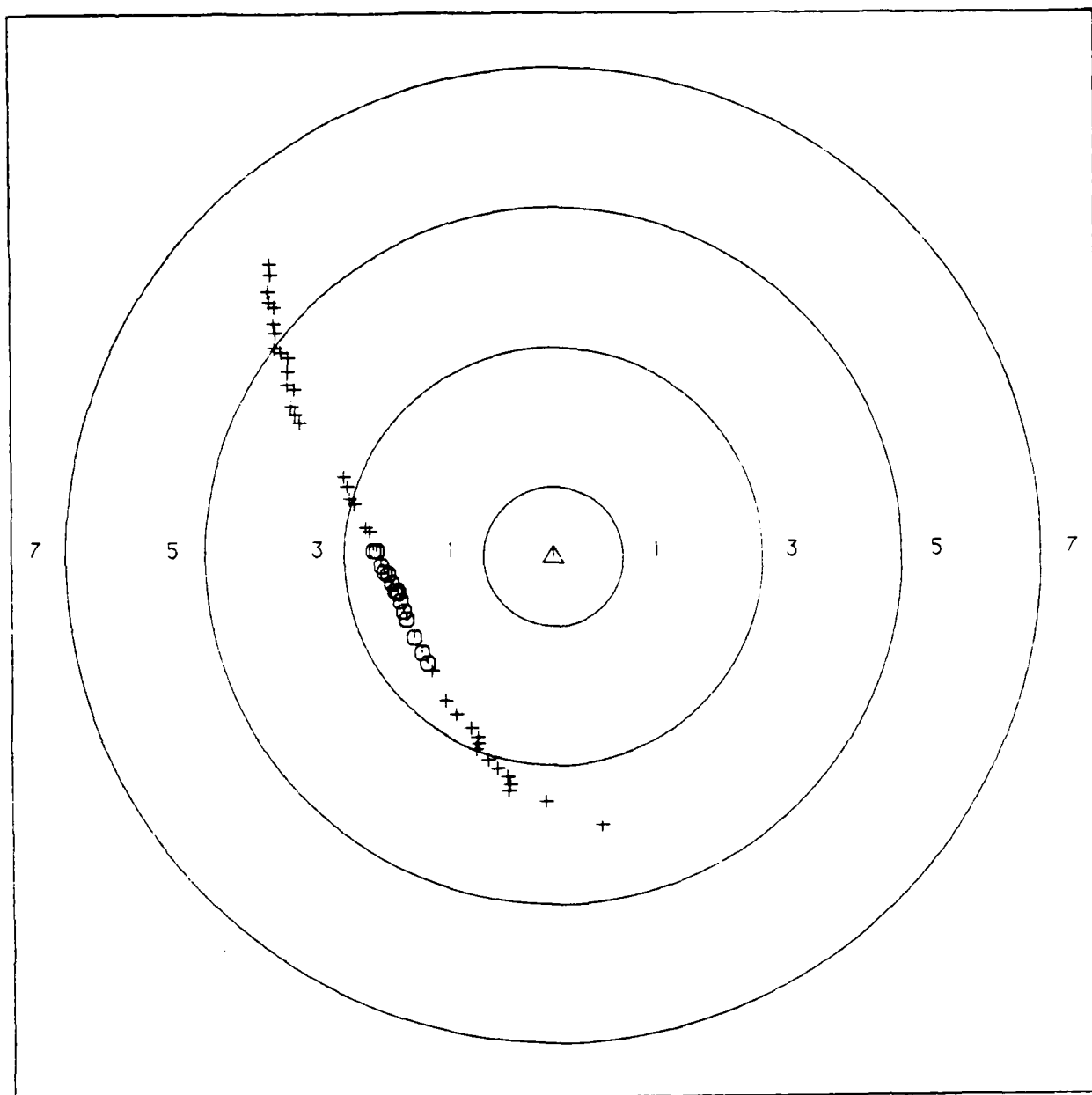


FIGURE D-39

TCAS WARNING 27: BEARING PLOT

[illegible]

} } }



D-69

28. TCAS WARNING 28

Warning 28 occurred while there was no observer on board the TCAS aircraft. The recorded data for this encounter are shown in Figures D-41 and D-42.

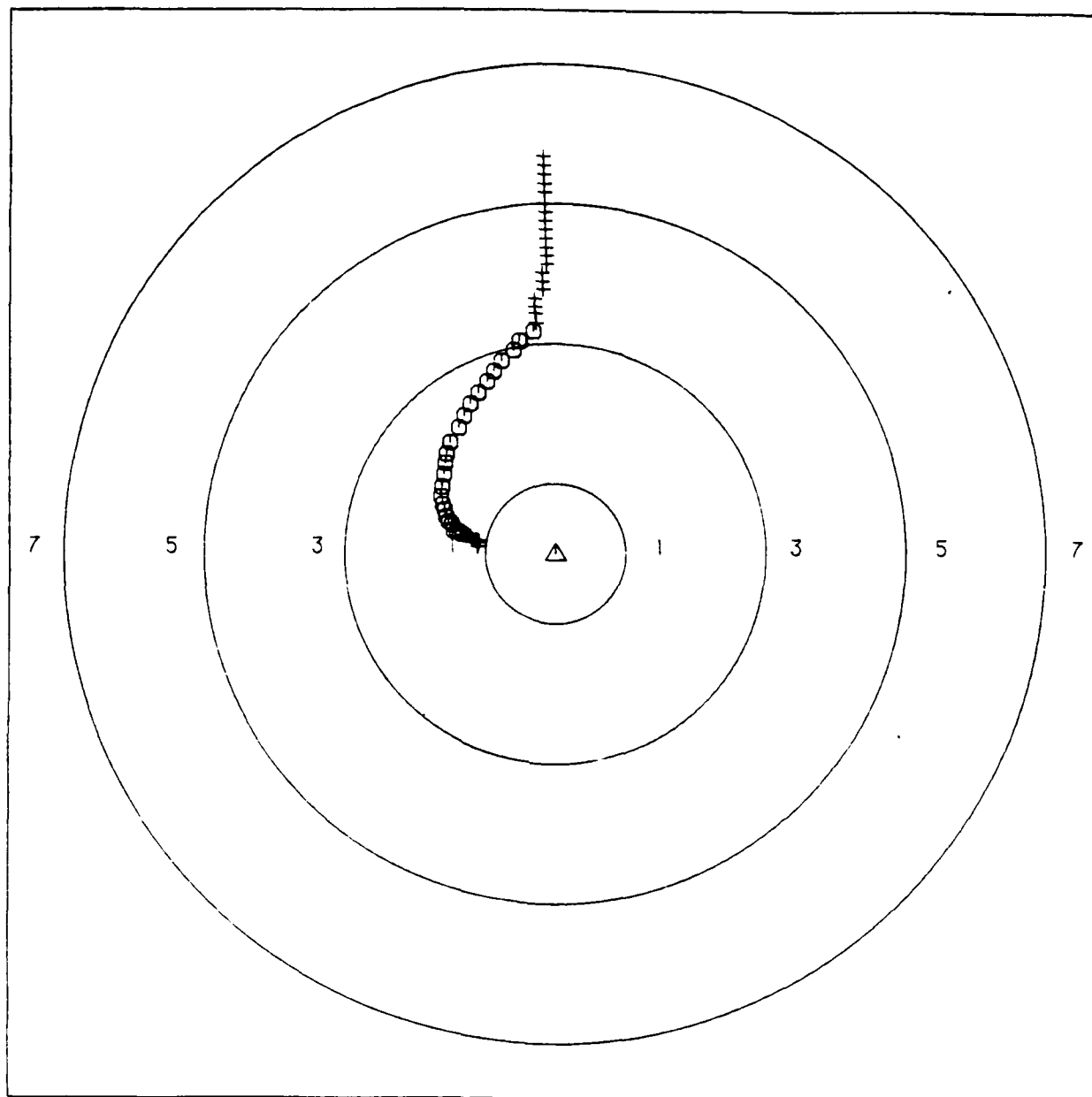


FIGURE D-41

TCAS WARNING 28: BEARING PLOT

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FLIGHT RA  -----↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑-----
MC SIM RA

```

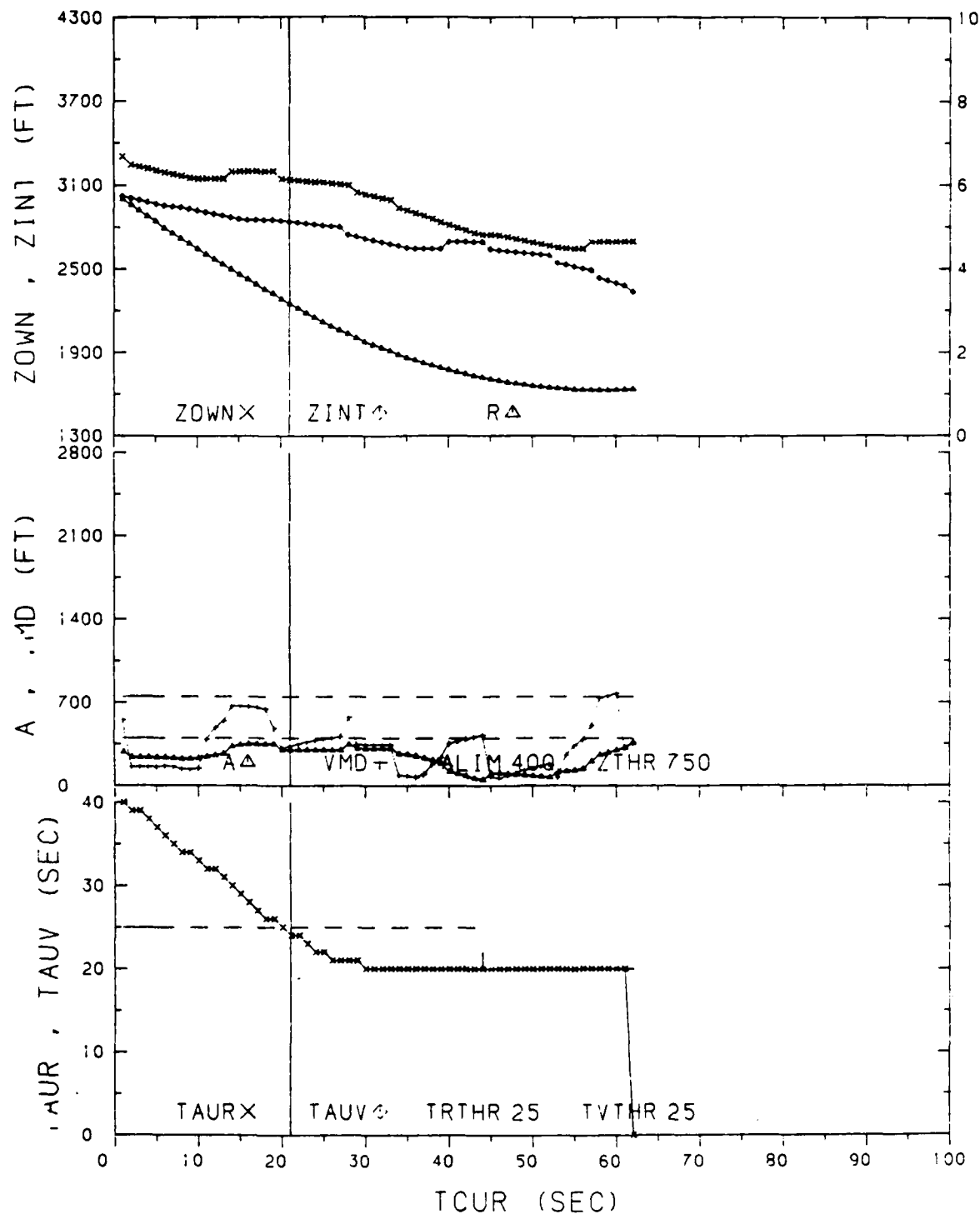


FIGURE D-42

TCAS WARNING 28: PARAMETERS

## 29. TCAS WARNING 29

On July 10, 1987, the TCAS aircraft was operating as Piedmont Flight 70 en route from Charlotte, North Carolina, to New York's LaGuardia airport. Approaching LGA, the aircraft had been cleared to descend to 7,000 feet by ATC and was established in a 1,000 fpm descent. At 1430Z, as the aircraft neared 9,000 feet, ATC instructed the crew to maintain 9,000 feet because of traffic. As Flight 70 leveled at 9,000 feet, TCAS issued a Caution showing an intruder at 11 o'clock, 1,100 feet, and climbing, with a range of approximately 2 miles. The crew asked ATC if the traffic TCAS alerted them to was the same as the traffic ATC had just given them; the response was negative. The TCAS intruder had closed to 1 mile laterally and 700 feet vertically when a CLIMB advisory was issued. The pilot established a 1,500 fpm rate of climb and deviated approximately 200 feet from the assigned altitude before the encounter cleared. After the Warning was removed, the pilot returned toward his assigned altitude. Flight conditions at the time were day, marginal VMC, with visibility about 3 miles in haze. The crew never gained visual contact with either the ATC-identified crossing traffic or the TCAS-identified intruder.

The data for this encounter are shown in Figure D-43.



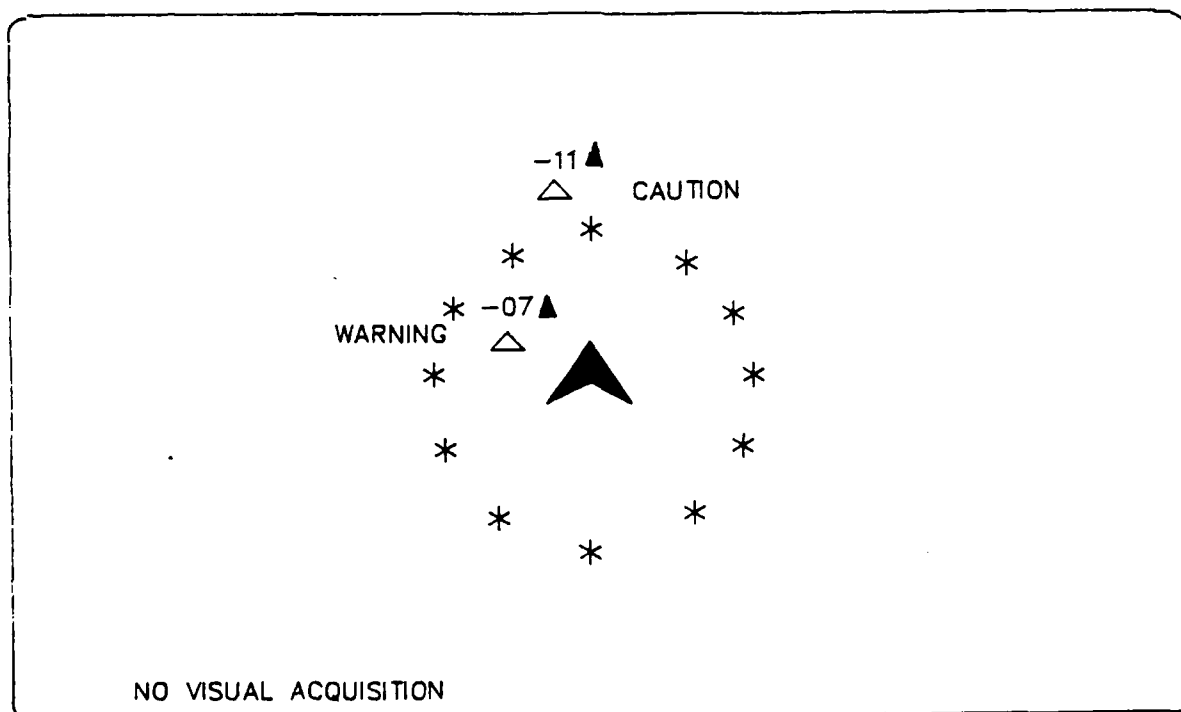
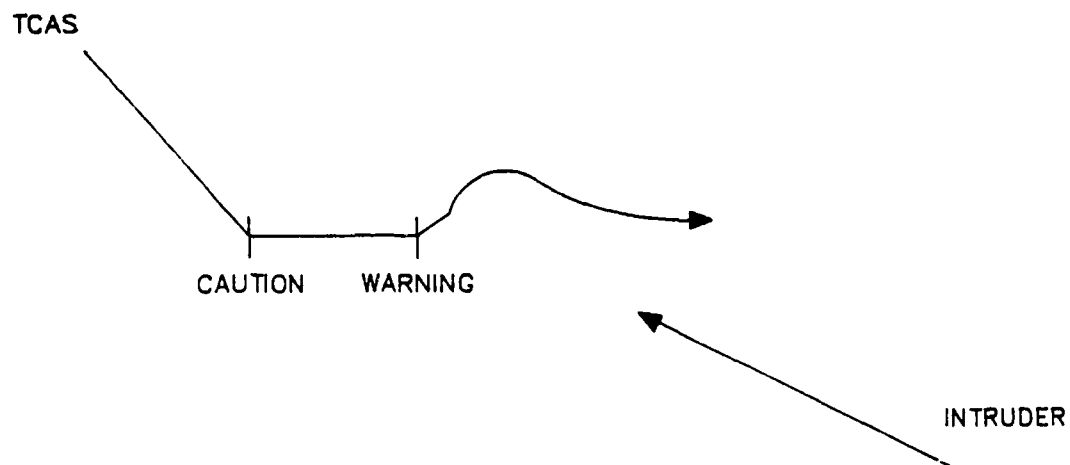


FIGURE D-43  
TCAS WARNING 29

### 30. TCAS WARNING 30

On July 10, 1987, Piedmont Flight 55 was en route to Richmond, Virginia, from New York's LaGuardia airport. At 1704Z, the flight was north of RIC, and ATC cleared it to descend to 10,000 feet. As the aircraft passed through 12,500 feet in a 3,000 fpm descent, ATC advised the crew of traffic at 1 o'clock and 2 miles. Shortly thereafter, TCAS issued a Warning to LIMIT VERTICAL RATE - DO NOT DESCEND and showed the intruder at 2 o'clock and 700 feet below Flight 55, passing along its right side. The pilot stopped the descent until the Warning cleared. There was no visual acquisition of the intruder, and the warning was not preceded by a Caution. Flight conditions at the time were day, marginal VMC, with visibility between 3 and 5 miles in haze.

The observer notes on this encounter are shown in Figure D-44.

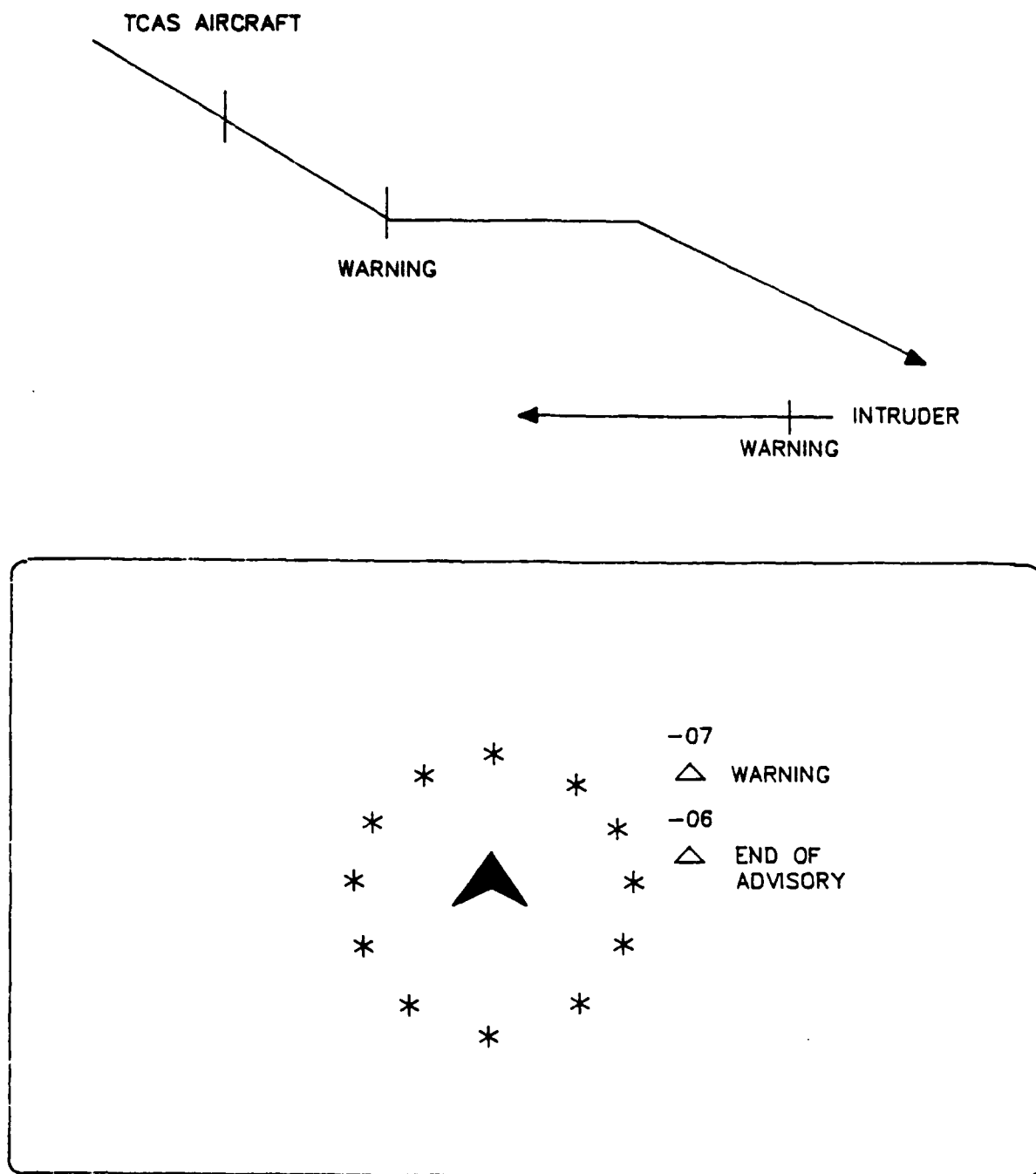


FIGURE D-44  
TCAS WARNING 30

### 31. TCAS WARNING 31

Warning 31 occurred while there was no observer on the TCAS aircraft. The recorded data for this encounter are shown in Figures D-45 and D-46.

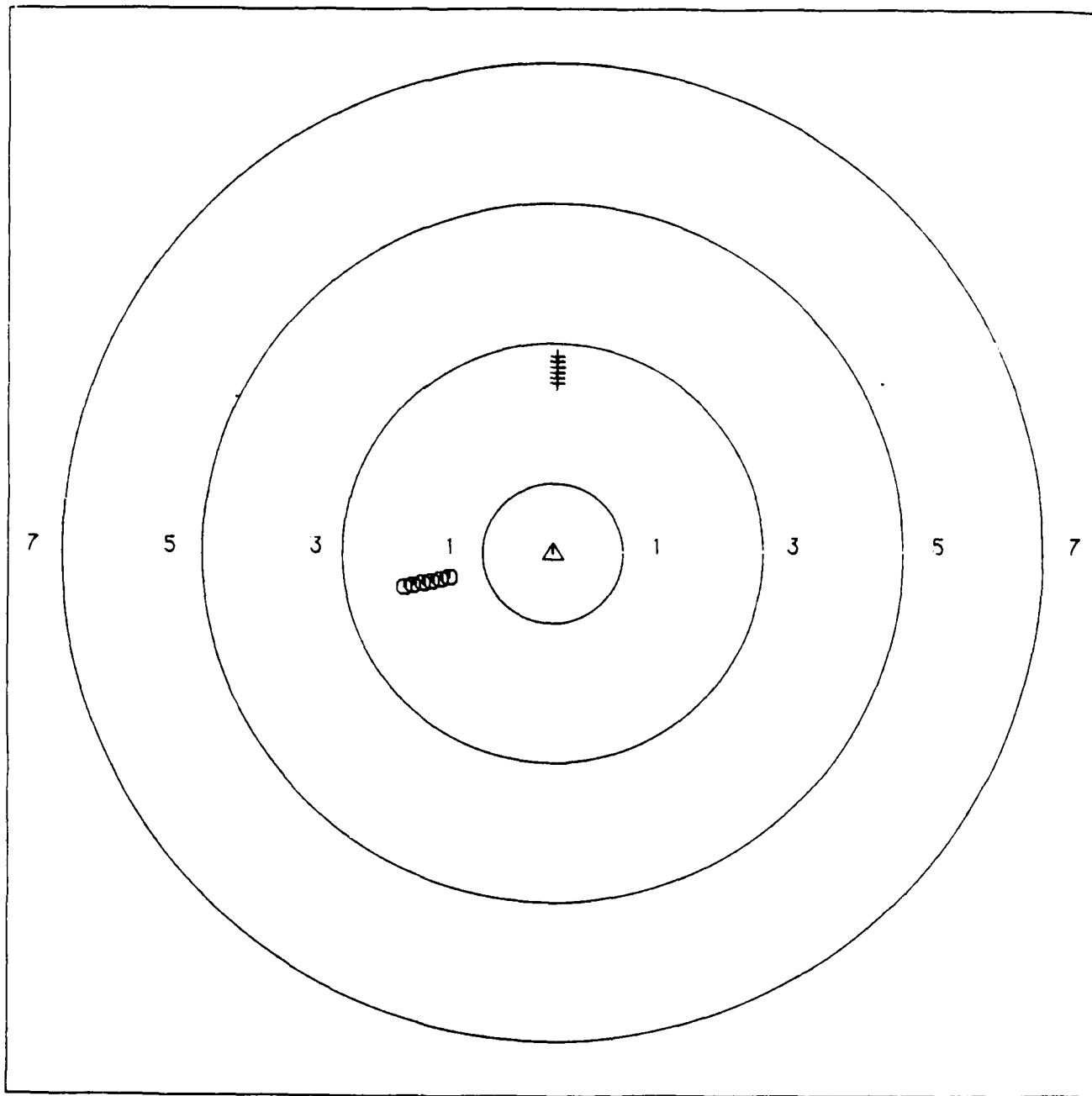
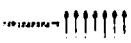


FIGURE D-45  
TCAS WARNING 31: BEARING PLOT

FLIGHT RA   
 MC SIM RA

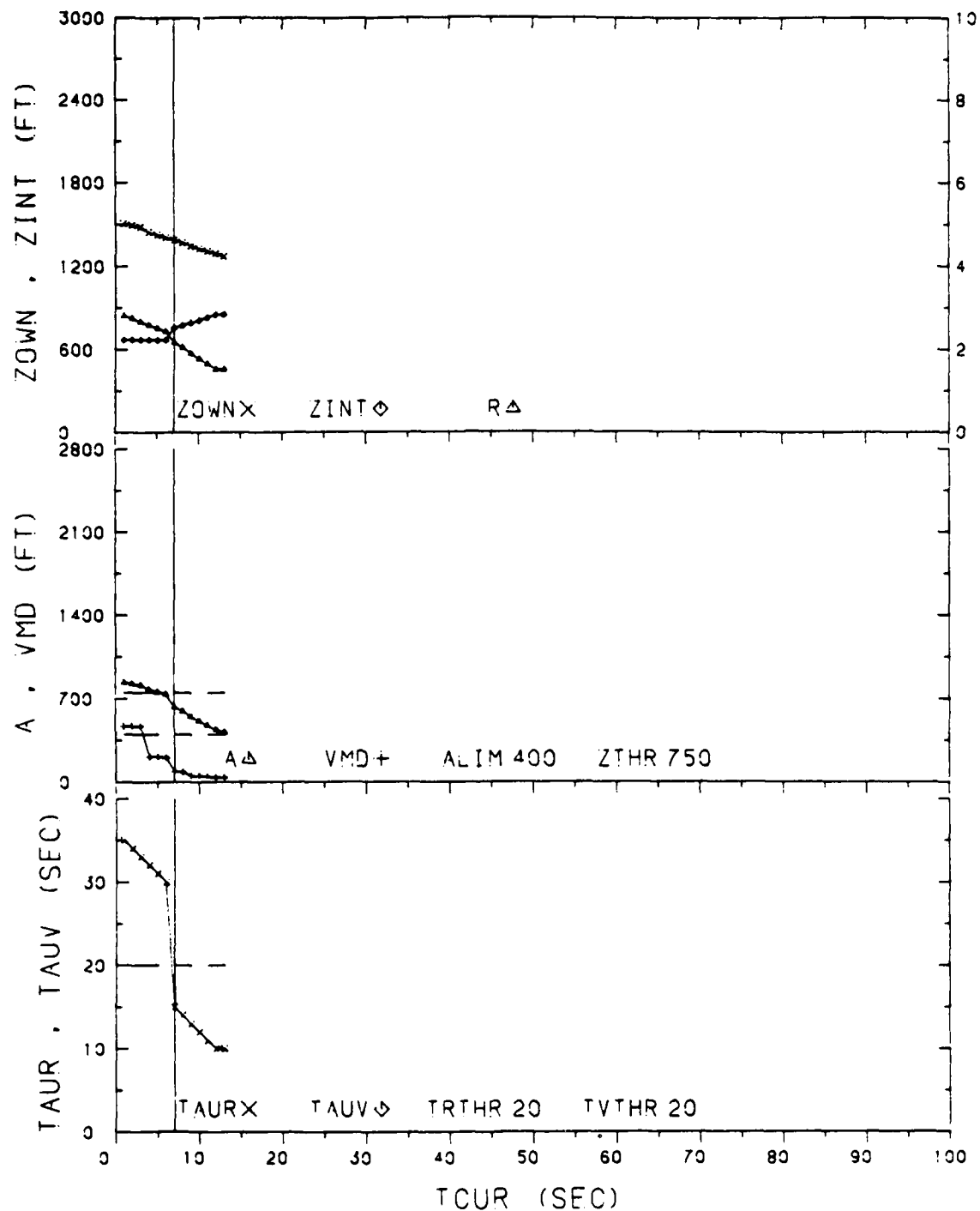


FIGURE D-46  
 TCAS WARNING 31: PARAMETERS

### 32. TCAS WARNING 32

Warning 32 occurred while there was no observer on board the TCAS aircraft. The recorded data for this encounter are shown in Figures D-47 and D-48.

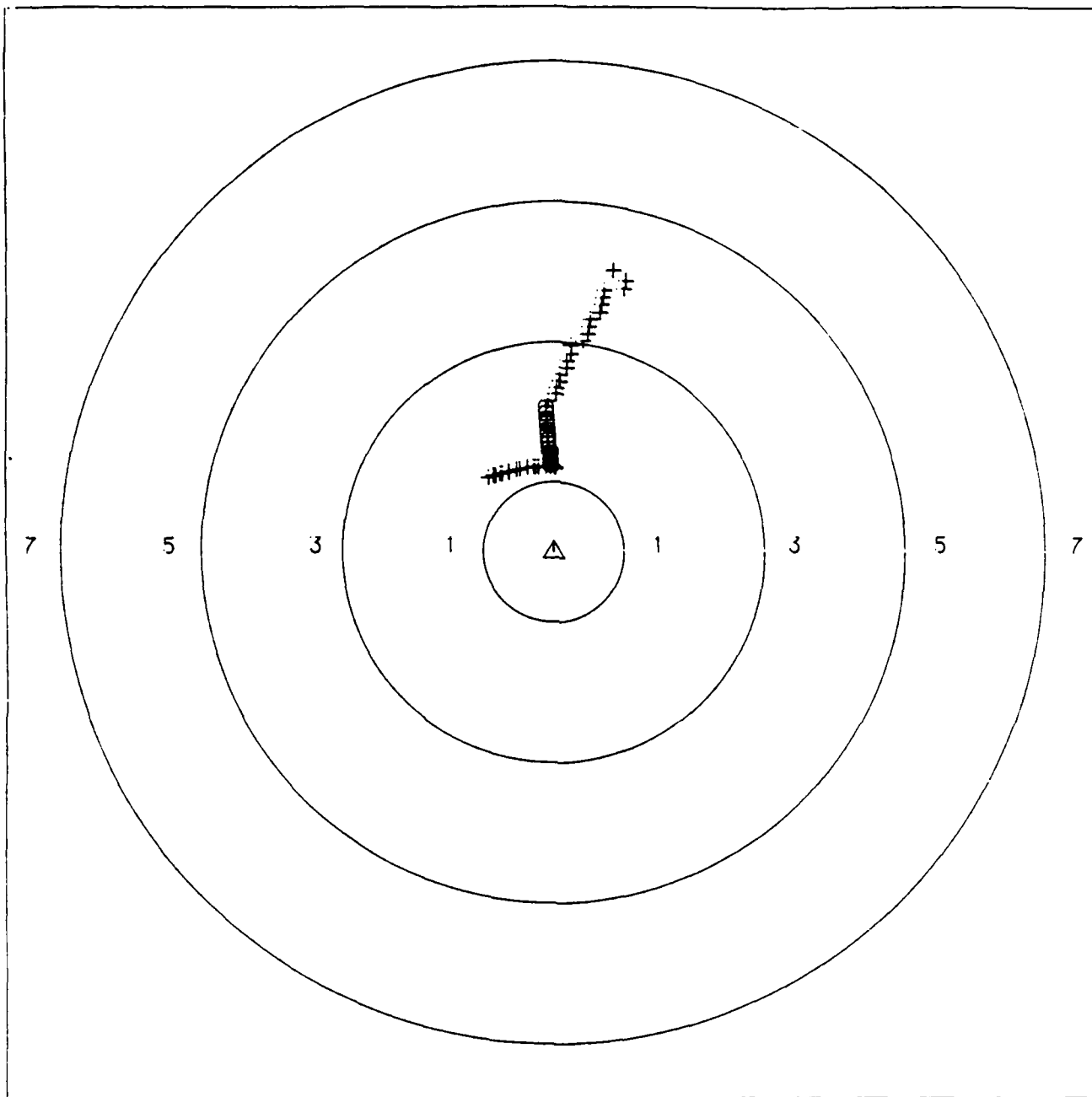


FIGURE D-47  
TCAS WARNING 32: BEARING PLOT



FLIGHT RA  
MC SIM RA

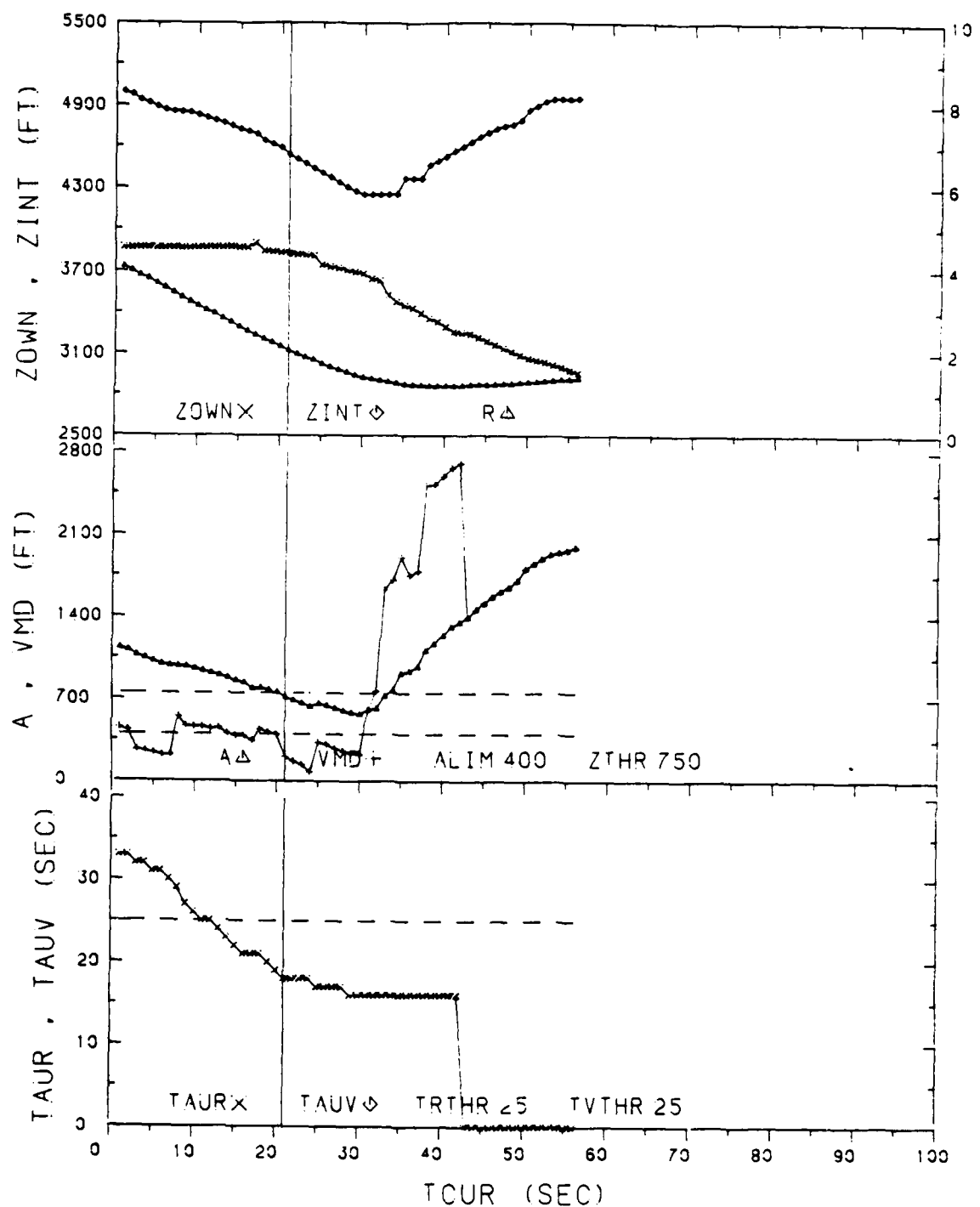


FIGURE D-48  
TCAS WARNING 32: PARAMETERS

### 33. TCAS WARNING 33

Warning 33 occurred while there was no observer on board the TCAS aircraft. The recorded data for this encounter are shown in Figures D-49 and D-50.

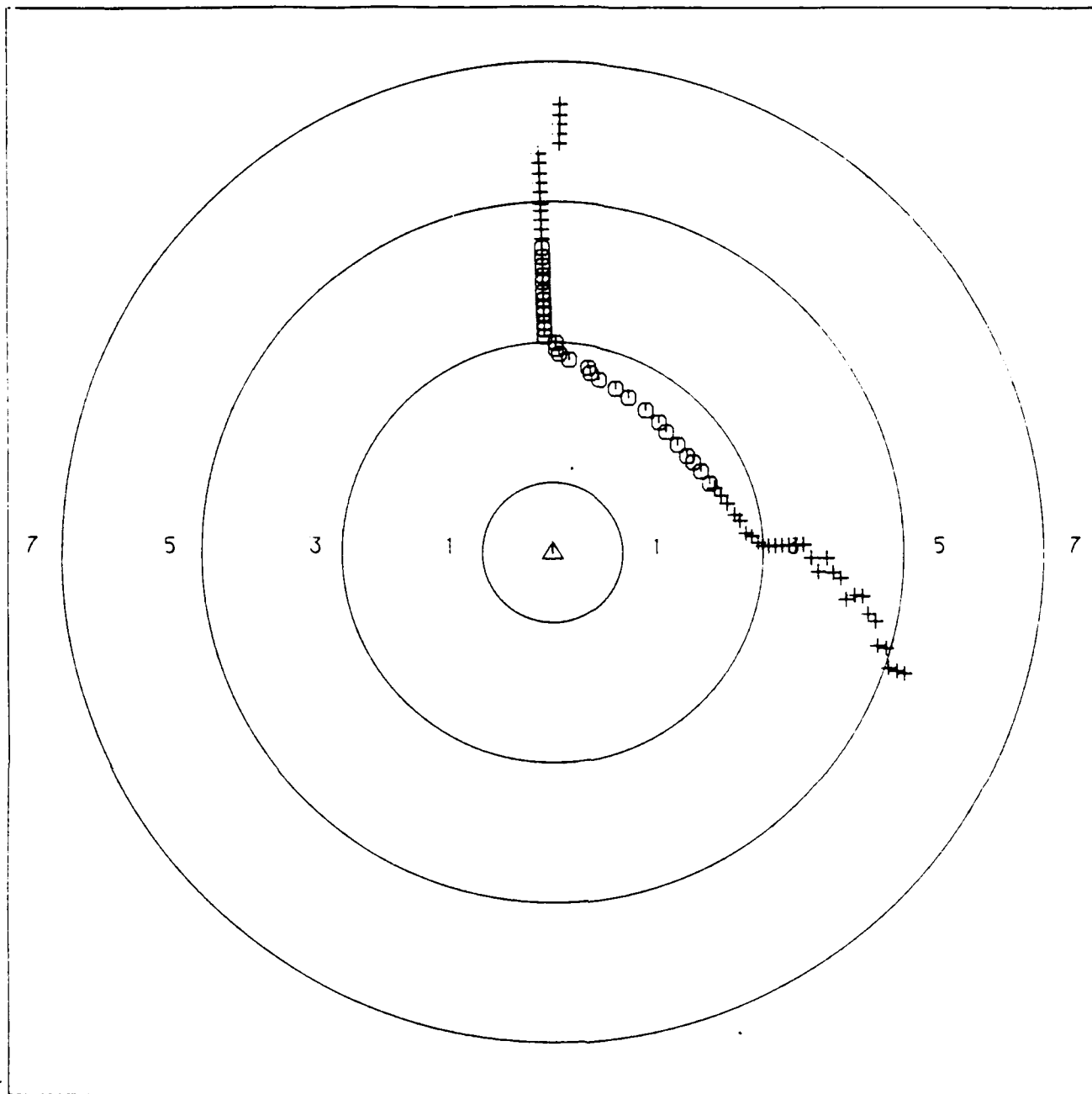


FIGURE D-49  
TCAS WARNING 33: BEARING PLOT

FLIGHT RA

MC SIM RA

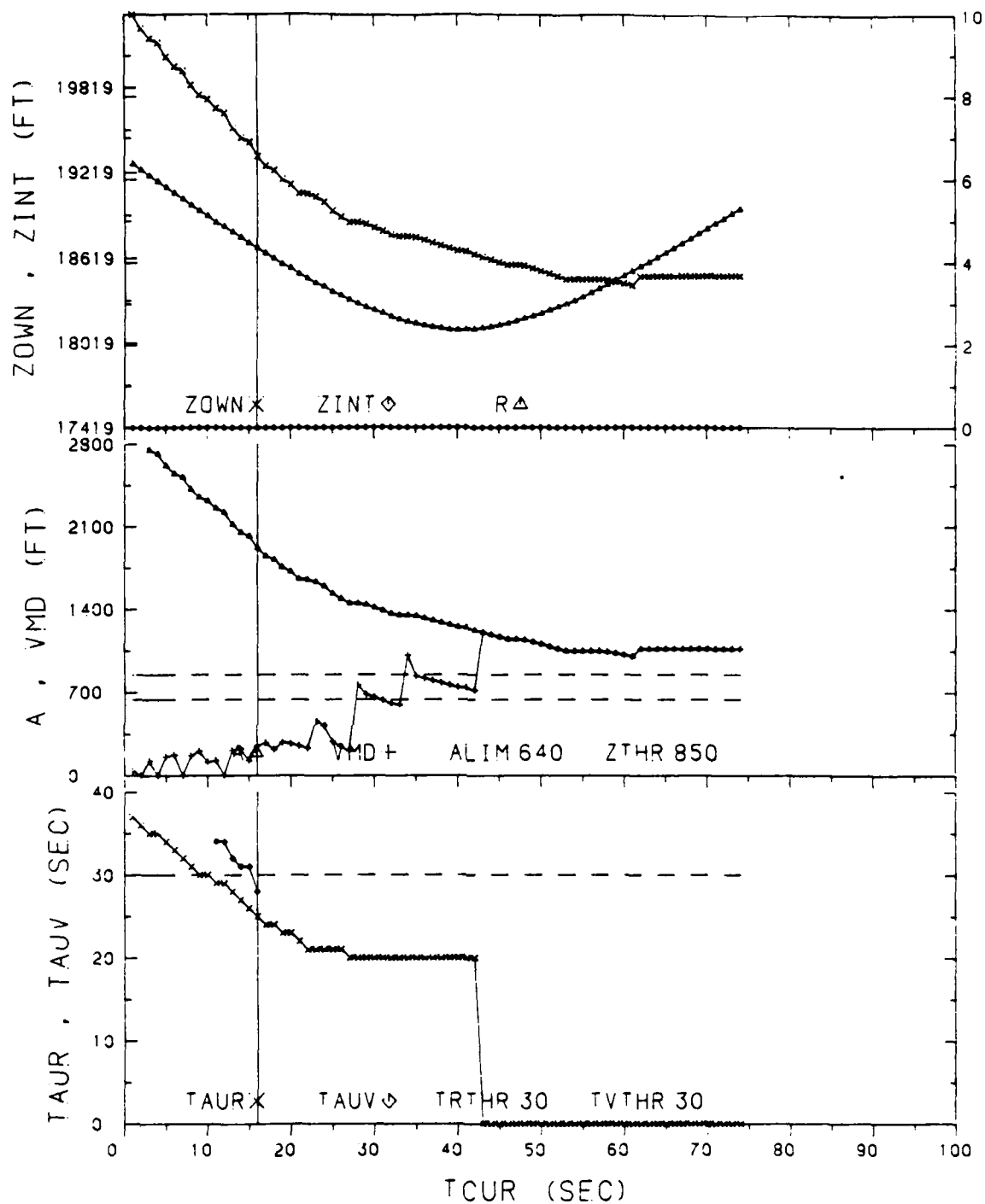


FIGURE D-50  
TCAS WARNING 33: PARAMETERS

#### 34. TCAS WARNING 34

On August 15, 1987, the TCAS aircraft was en route from Charlotte, North Carolina, to Newark, New Jersey, operating as Piedmont Flight 56. The aircraft was approximately 15 miles southwest of Newark on the RBV (Robbinsville) 240 degree radial, descending at 4,500 fpm to its assigned altitude of 11,000 feet. At 1420Z, as the aircraft was passing 15,000 feet, TCAS issued a Caution showing traffic at 1 o'clock, 3,200 feet below and climbing, at a range of approximately 5 miles. When the intruder's range closed to within 2 miles and the altitude difference was 1,700 feet, a TCAS Warning to LIMIT VERTICAL RATE - DO NOT DESCEND GREATER THAN 2,000 FPM was issued. The crew acquired the intruder visually, and the pilot decreased the descent rate from 4,500 fpm to 2,000 fpm. When the intruder's altitude was 1,100 feet below Flight 56's, the Warning cleared. ATC advised the crew of the traffic, level at 10,500 feet, after the Warning was cleared. Flight conditions were day, VMC, with visibility greater than 20 miles.

The observer notes on this encounter are shown in Figure D-51.

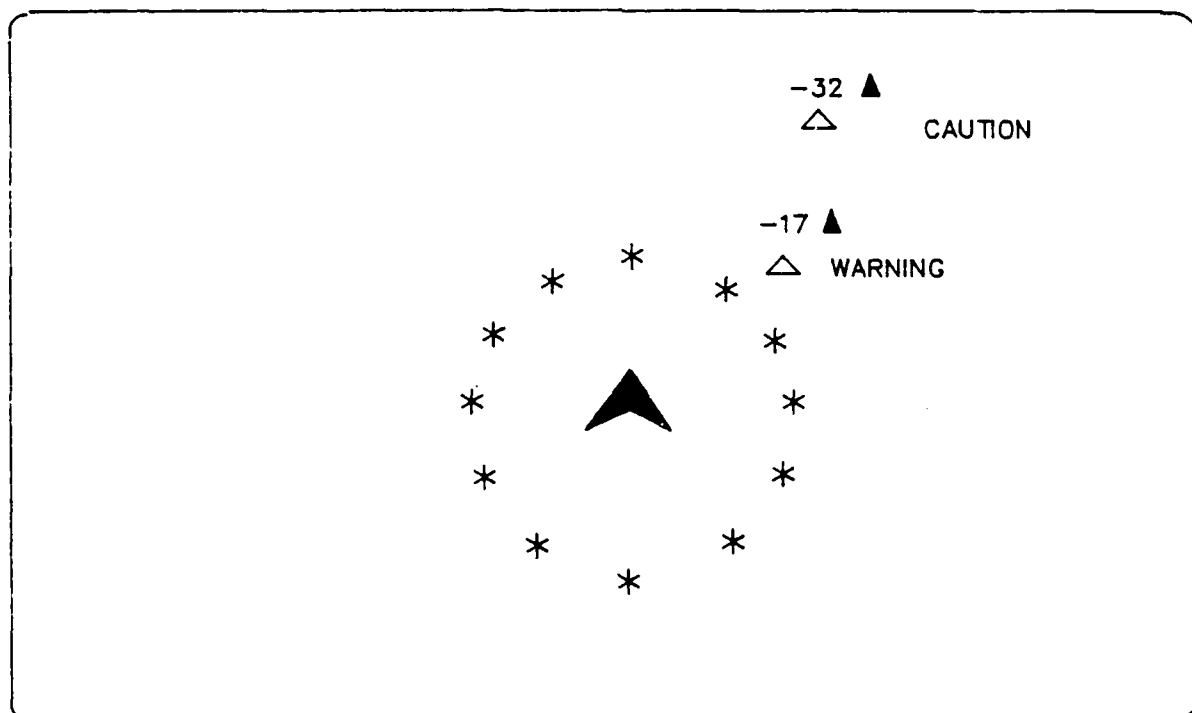
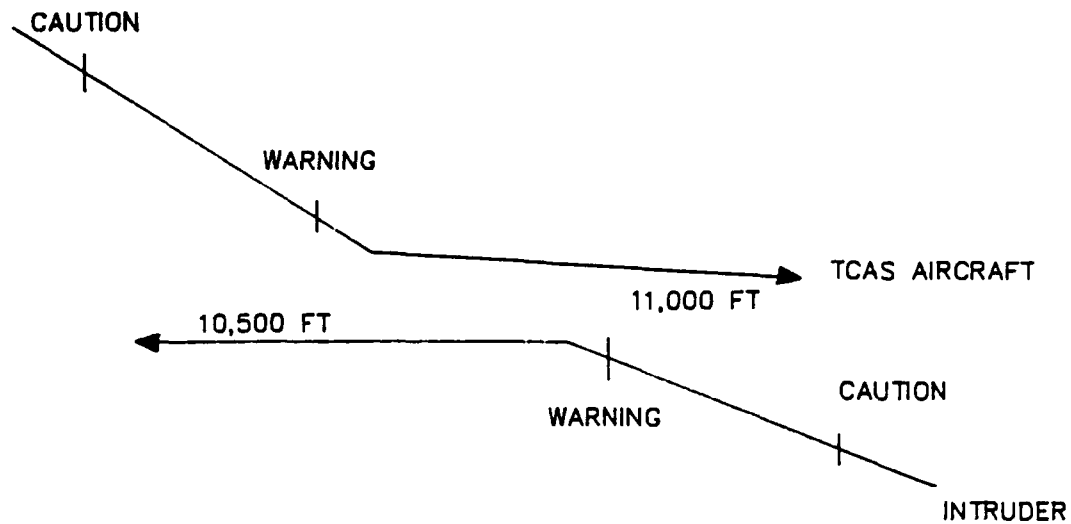


FIGURE D-51  
TCAS WARNING #34

### 35. TCAS WARNING 35

On August 5, 1987, Piedmont Flight 125 was en route to Ft. Lauderdale, Florida, from Charlotte, North Carolina. At 2121Z, the aircraft was established on final for landing at FLL. The flaps were set at 25 degrees and the landing gear was down. Flight conditions were day, VMC, with visibility greater than 15 miles. As the aircraft crossed the outer marker, ATC advised the crew of traffic on a downwind leg that would be following Flight 125 to the runway. The crew visually acquired the traffic and continued the approach. Approximately 3 miles from the runway, TCAS issued a Caution showing the pattern traffic at approximately 11 o'clock, at a range of 2 miles, and 200 feet below. When the intruder closed to 1 mile and 100 feet below, a CLIMB advisory was issued. The pilot then selected 30 degrees of flaps, which cleared the Warning by inhibiting the display. In the opinion of both the observer and the flight crew, the Caution and Warning were unnecessary and distracting at a critical point in the flight (short final).

The recorded data for this encounter are shown in Figures D-52 and D-53.

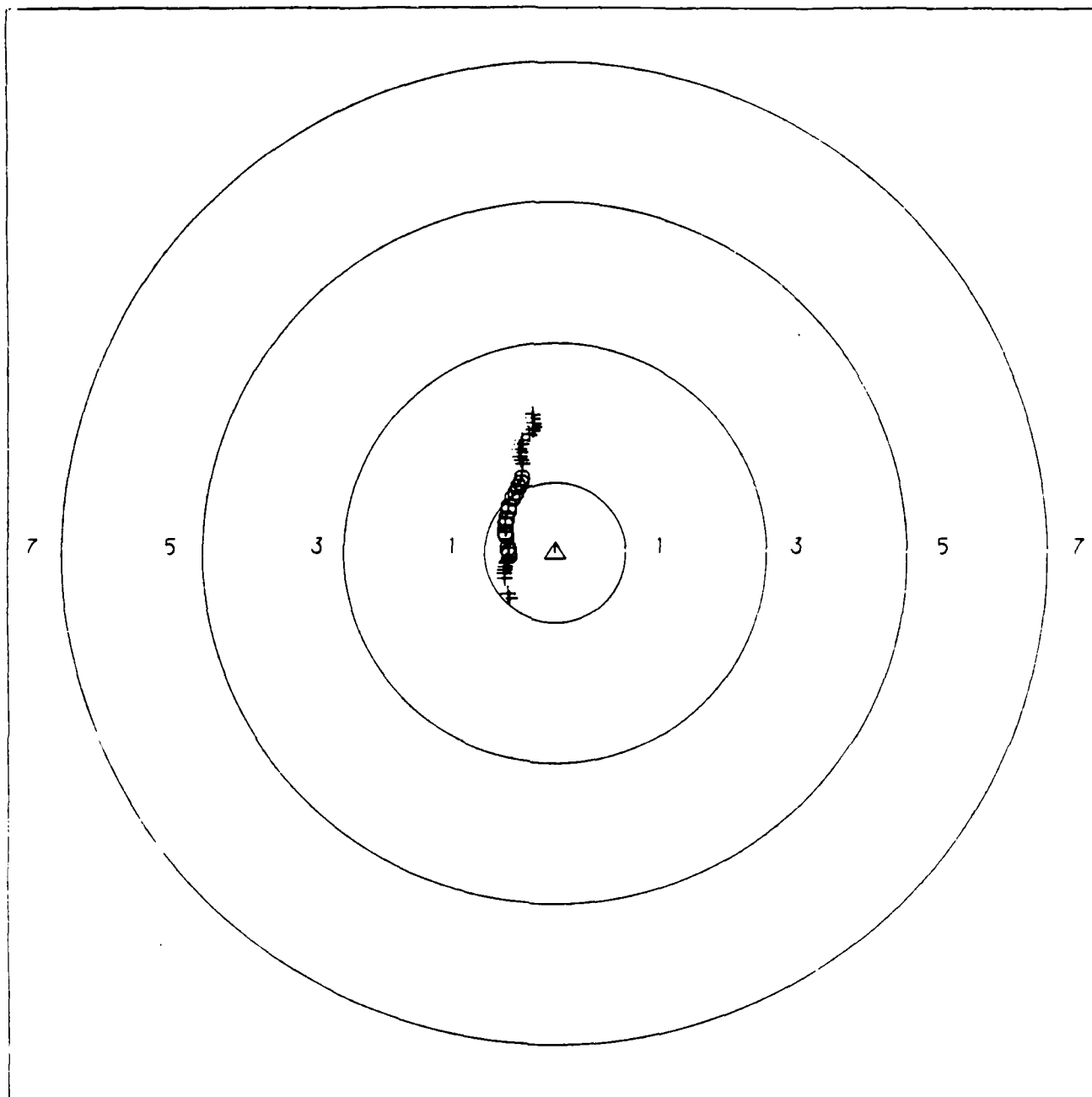


FIGURE D-52  
TCAS WARNING 35: BEARING PLOT



MC SIM RA

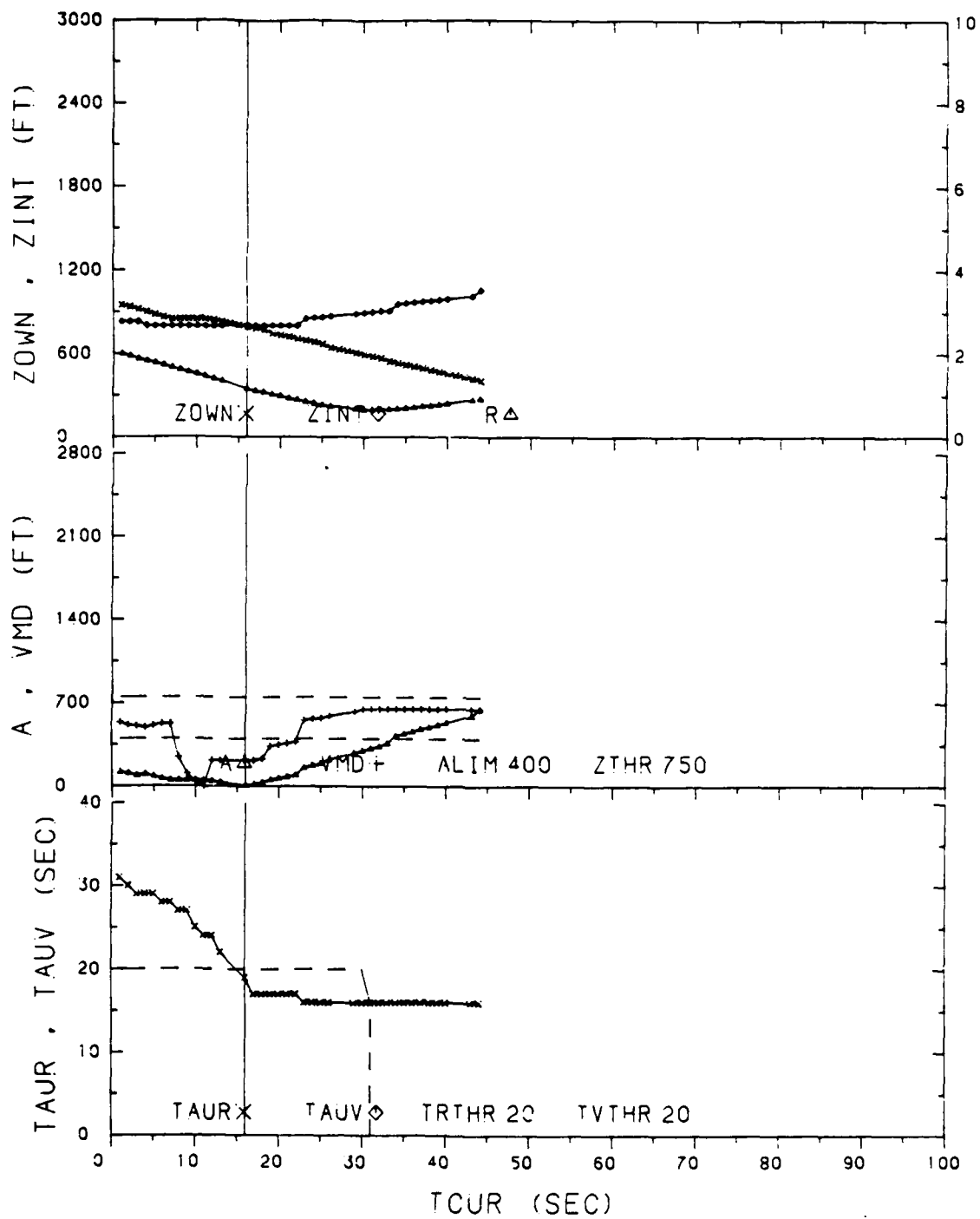


FIGURE D-53

TCAS WARNING 35: PARAMETERS

### 36. TCAS WARNING 36

On August 12, 1987, Piedmont Flight 64 was en route to Charlotte, North Carolina, from Charleston, South Carolina. The aircraft was under the positive control of Charlotte ATC and was maneuvering in the terminal area for a turn on to final approach for landing. At 1215Z, the aircraft had been cleared for a visual approach to runway 36R, and ATC advised the crew of traffic making an approach to the parallel runway. The crew had not yet acquired the traffic visually when TCAS issued a Caution showing traffic at 11 o'clock, 200 feet above, and descending. The crew then visually acquired the traffic and continued the descent and the turn to the final approach course. As Flight 64 descended through 6,000 feet, and with the intruder closing to within 2 miles, TCAS issued a Warning to DESCEND. The crew maintained their descent rate of 2,500 fpm, and the encounter cleared. Flight conditions at the time were day, marginal VMC, with visibility between 5 and 7 miles in haze.

The available data for this encounter are shown in Figure D-54.

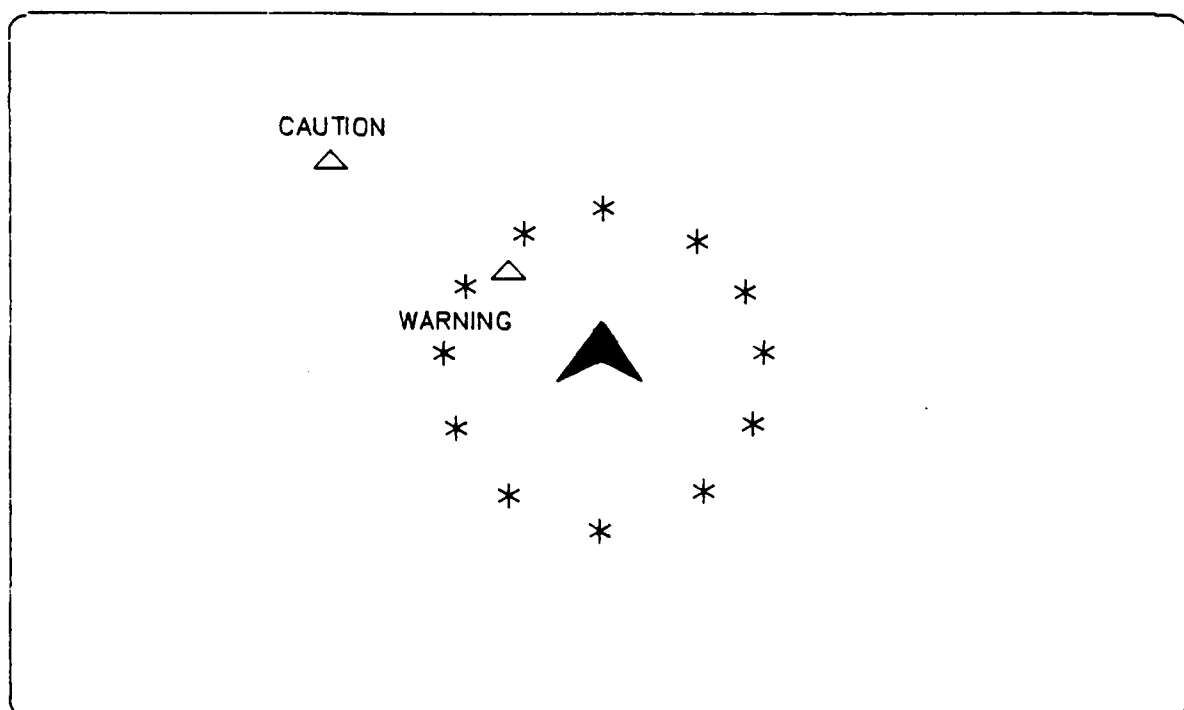
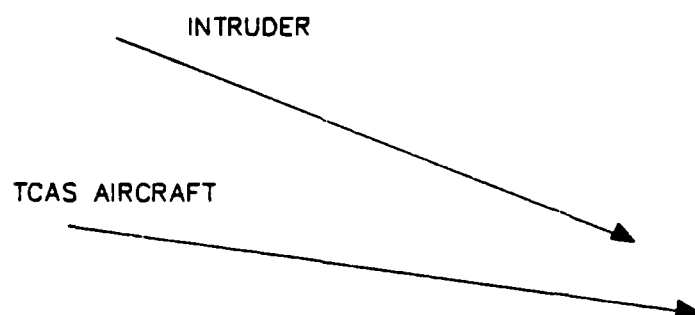


FIGURE D-54  
TCAS WARNING 36

### 37. TCAS WARNING 37

On September 10, 1987, the TCAS aircraft was operating as Piedmont Flight 56 between Orlando, Florida, and Charlotte, North Carolina. While the aircraft was flying level at 13,000 feet and approximately 10 nm north of the Orlando airport, a Caution was issued against an intruder at the 12 o'clock position in level flight at 13,500 feet. The intruder was beyond the display range of the CRT and was shown as a square at the 12 o'clock position. No action was taken by the crew, and the crew was unable to visually acquire the intruder. A Warning followed that advised the crew to LIMIT VERTICAL RATE - DO NOT CLIMB while the TCAS aircraft was approximately 1,000 feet below and 5 nm from the intruder. At the time the Warning was issued, the TCAS aircraft was climbing at a rate of approximately 1,800 fpm. In response to the DO NOT CLIMB Warning, the climb rate was reduced to approximately 1,200 fpm and the climb continued until the TCAS aircraft leveled-off at 13,000 feet. (The observer data did not mention the LIMIT VERTICAL RATE Warning so no information was available on why the crew continued to climb). As the TCAS aircraft leveled-off, the Warning was strengthened to DESCEND. The crew responded to this advisory and descended approximately 350 feet from the assigned altitude of 13,000 feet. The encounter ended with the intruder aircraft at the 4 o'clock position and 800 feet above the TCAS aircraft. The TCAS aircraft then began returning to its original altitude of 13,000 feet.

Figures D-55 and D-56 show the recorded data for this Warning.

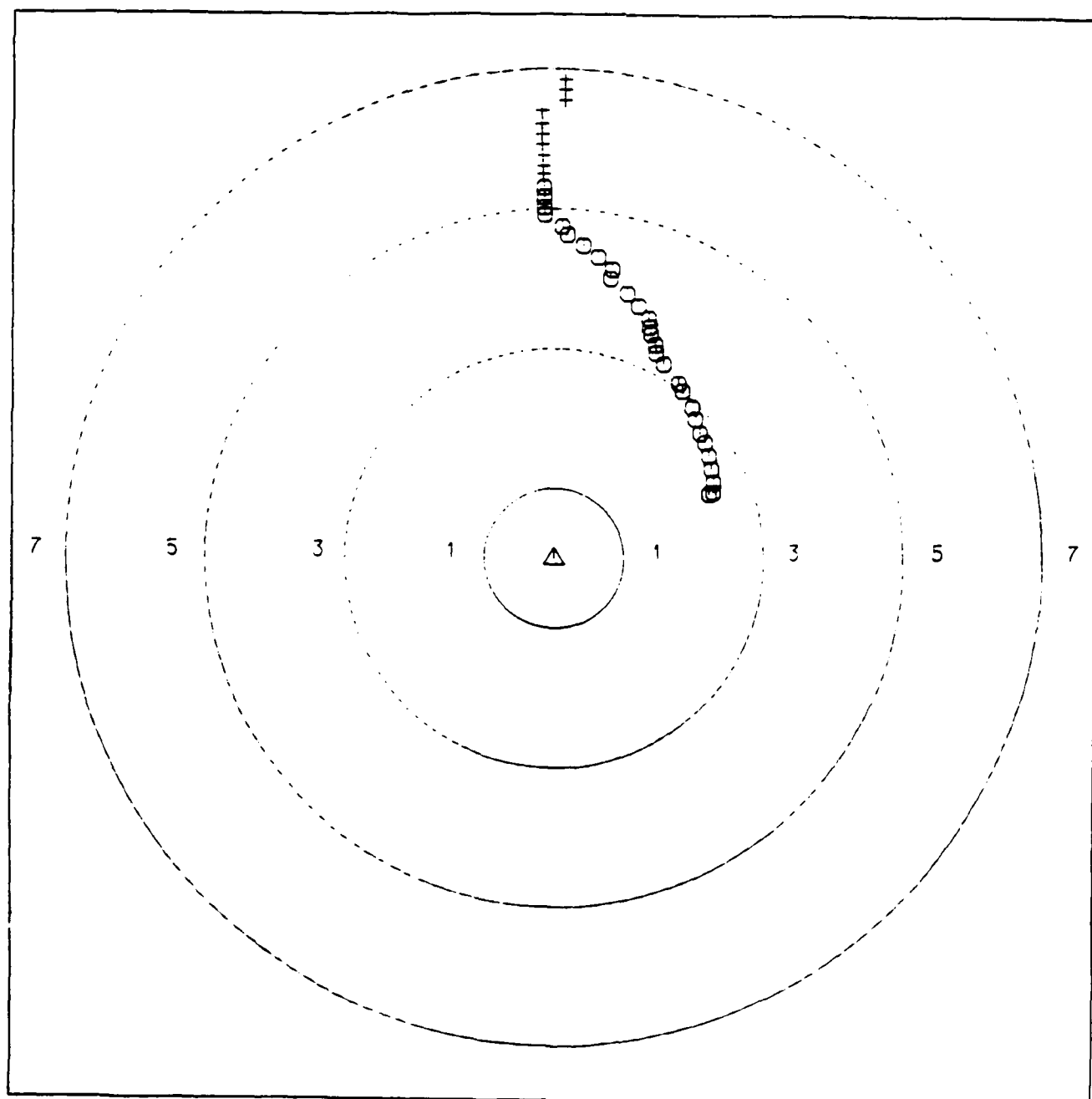


FIGURE D-55  
TCAS WARNING 37: BEARING PLOT

FLIGHT RA .....  
 MC SIM RA .....

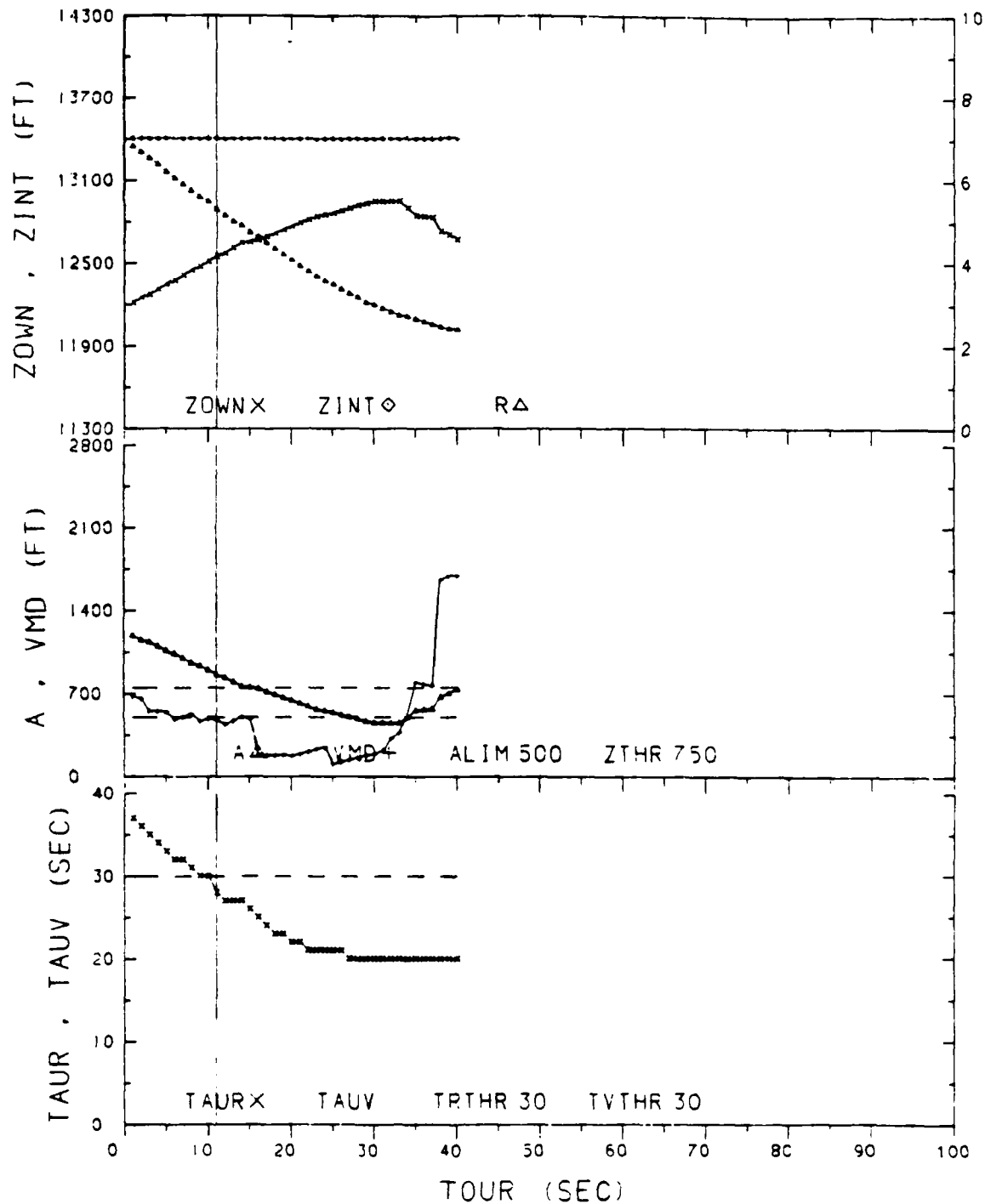


FIGURE D-56  
 TCAS WARNING 37: PARAMETERS

### 38. TCAS WARNING 38

On September 16, 1987, the TCAS aircraft was operating as Piedmont Flight 34 en route to Newark, New Jersey, from Boston, Massachusetts. At 2316Z the aircraft was established on final approach for landing on runway 22L at EWR. The landing gear was down and the flaps were set at 25 degrees. When the aircraft was approximately 1 mile from touchdown at an altitude of 1,200 feet, TCAS issued a Caution showing traffic at 12 o'clock, 500 feet below, and closer than 1 mile. The crew visually acquired a helicopter on final approach to runway 22R. TCAS then issued a CLIMB advisory against the intruder, which was shown at 1 o'clock and 300 feet below the TCAS aircraft. Since the traffic was in sight and its intentions were clear, the advisory was disregarded. Flight conditions at the time were day, marginal VMC, with visibility 3 to 5 miles.

The recorded data from this encounter is shown in Figures D-57 and D-58.

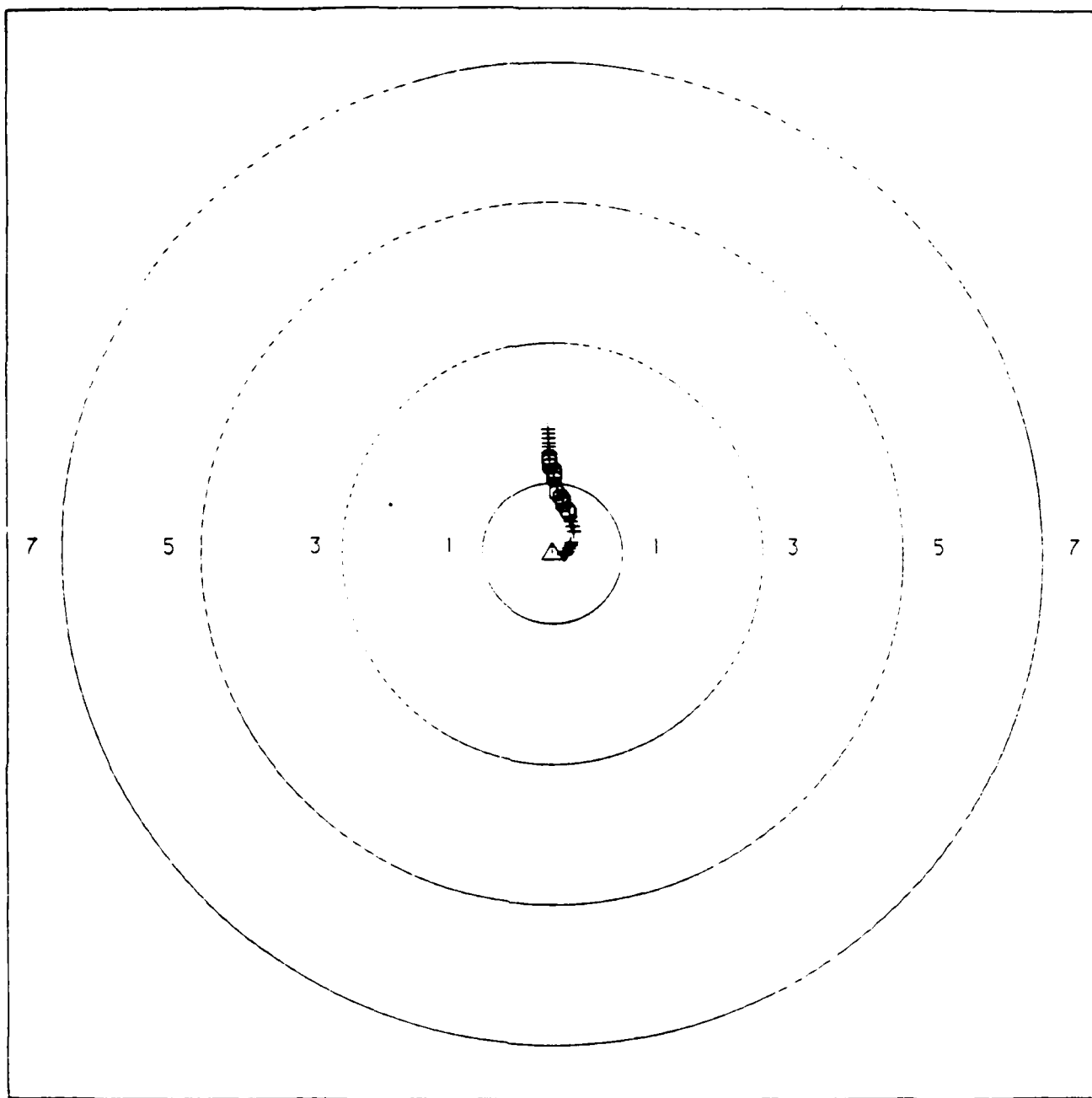


FIGURE D-57  
TCAS WARNING 38: BEARING PLOT



FLIGHT RA .....  
 MC SIM RA

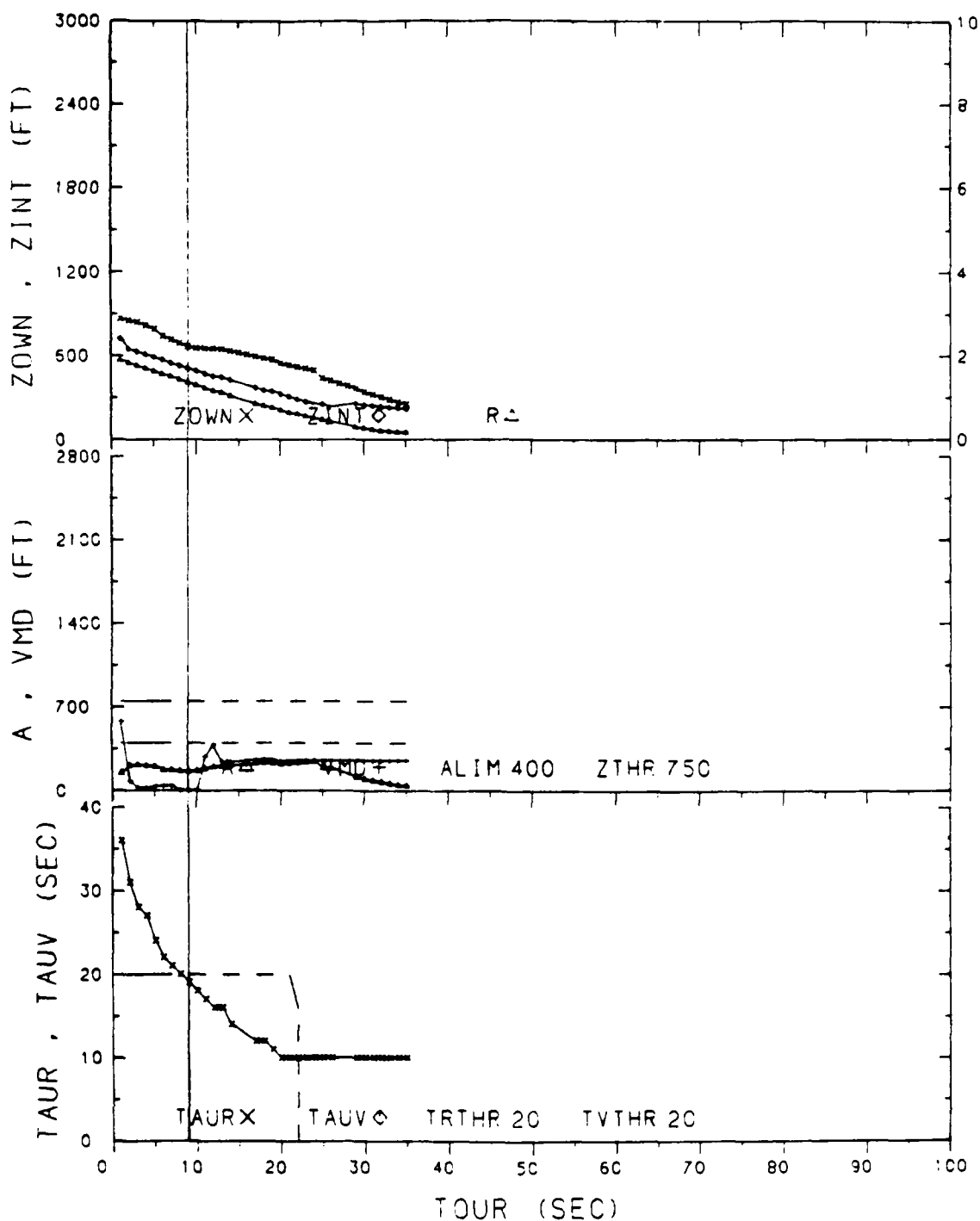


FIGURE D-58  
 TCAS WARNING 38: PARAMETERS

### 39. TCAS WARNING 39

On September 17, 1987, Piedmont Flight 80 was scheduled to provide service between Norfolk, Virginia, and Newark, New Jersey. At 2033Z the aircraft was climbing through 2,000 feet at a rate of 2,000 fpm en route to its clearance altitude of 5,000 feet. ATC requested that the crew expedite the climb through 3,000 feet just prior to a TCAS Caution. The Caution showed traffic ahead of and below the aircraft and climbing. The CRT display also showed a Proximate target off each wing. As the traffic ahead closed to within a mile and the altitude separation indicated 900 feet, a CLIMB Warning was issued. The pilot maintained the 2,000 fpm climb, and as Flight 80 passed through 4,000 feet, the Warning was removed. The crew visually acquired one of the Proximate targets but not the target against which the Warning was issued. ATC did not give any instruction other than to expedite the climb. Flight conditions were day, VMC, with visibility greater than 20 miles.

The observer data for this encounter are shown in Figure D-59.

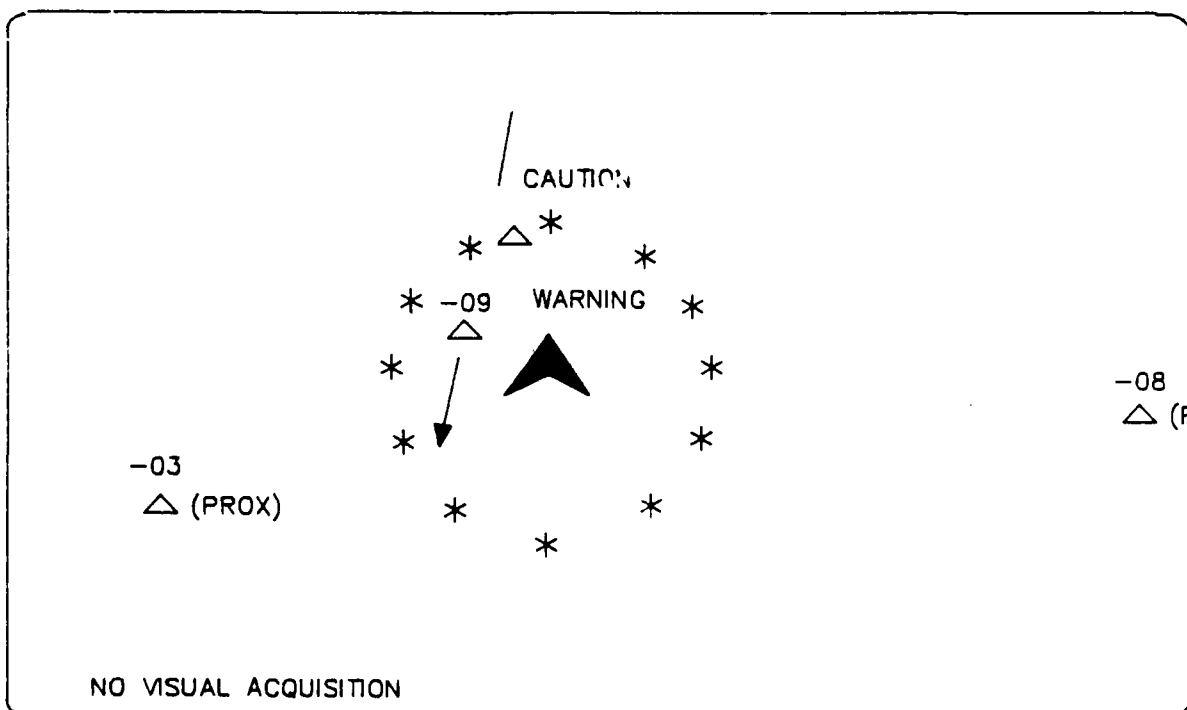
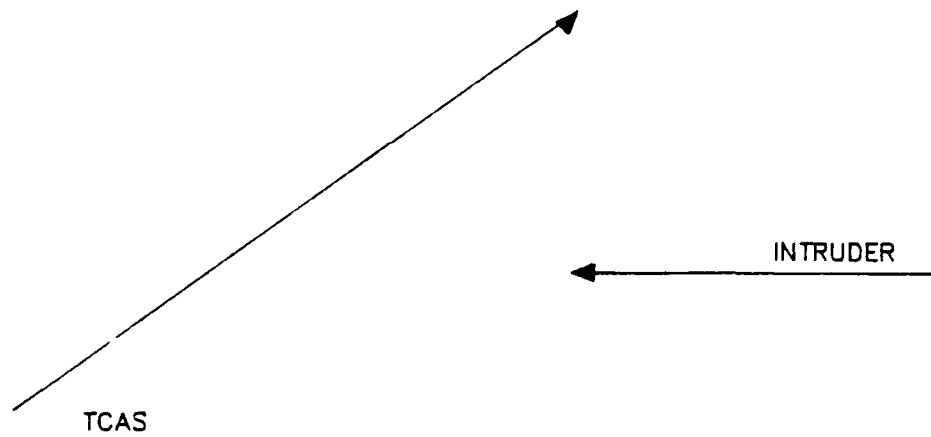


FIGURE D-59  
TCAS WARNING 39

#### 40. TCAS WARNING 40

On September 22, 1987, Piedmont Flight 114 was descending into the Charlotte, North Carolina, terminal area en route from Cleveland, Ohio. At 1640Z the aircraft was on the CLT 310 degree radial at 8 DME when ATC issued an advisory of traffic at 12 o'clock and below, at a range of 4 miles. As the crew initiated a visual search for the traffic, TCAS issued a Caution showing the traffic 1,200 feet below and level, at 12 o'clock, and at a range of 4 miles. The intruder continued to track toward Flight 114, and when it was at 3 o'clock and 400 feet below, a CLIMB Warning was issued. The crew had just acquired the traffic visually and determined that no action was necessary, so they elected to not respond to the Warning. Flight conditions were day, VMC, with visibility greater than 10 miles.

Figure D-60 shows the available data for this encounter.

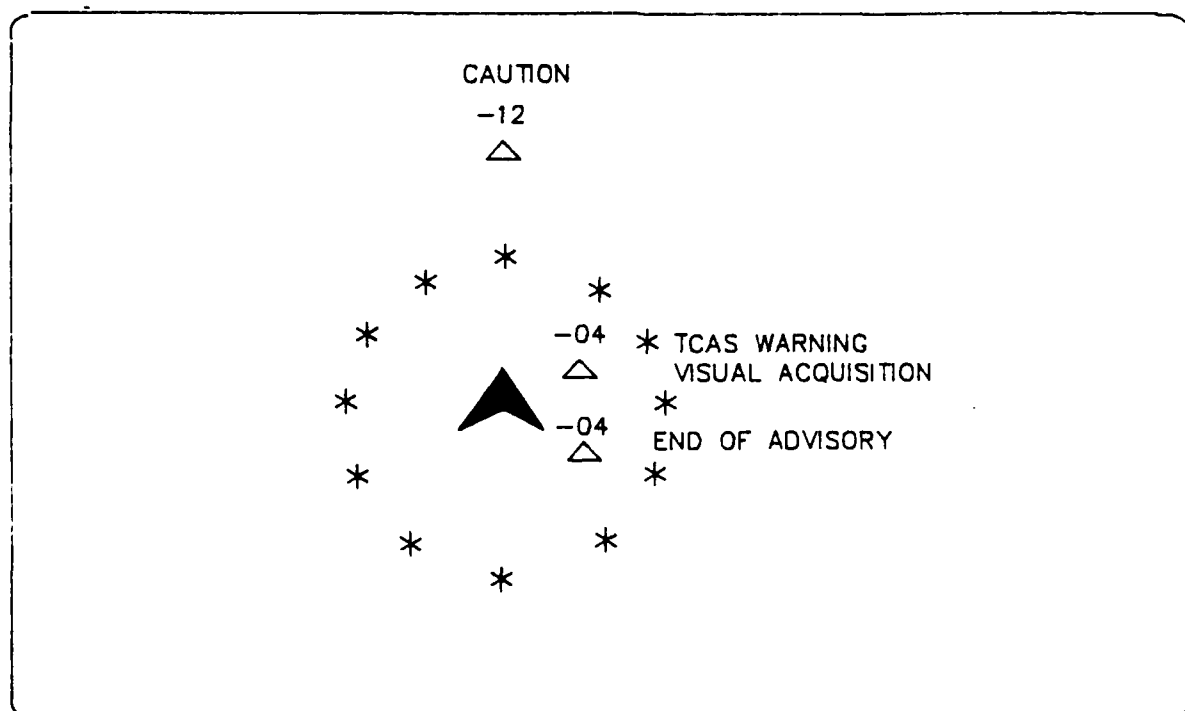


FIGURE D-60  
TCAS WARNING 40

#### 41. TCAS WARNING 41

On September 30, 1987, Piedmont Flight 69 was en route from Cleveland, Ohio, to Charlotte, North Carolina. At 2358Z the aircraft was flying an extended downwind leg for landing on runway 36L. As Charlotte Approach Control cleared the aircraft to turn for its base leg, it advised the crew of traffic making a simultaneous approach to the parallel runway (36R). The crew acquired the traffic visually and proceeded with the approach. As both aircraft began their turns onto the final approach course, TCAS issued a Caution showing the pattern traffic at approximately 1 o'clock. The intruder continued to track toward Flight 69, and at a range of approximately 2 miles, a LIMIT VERTICAL RATE - DO NOT DESCEND >500 FPM Warning was issued, quickly followed by a CLIMB Warning. The TCAS aircraft and intruder aircraft were on a parallel course and at approximately the same speed which resulted in the Warning being displayed for 35 seconds. Since the pilot had visual contact with the traffic and was cleared to maintain visual separation with the intruder, the TCAS Warnings were not followed. Flight conditions were night, VMC, with visibility greater than 5 miles.

Figures D-61 and D-62 show the recorded data for this encounter.

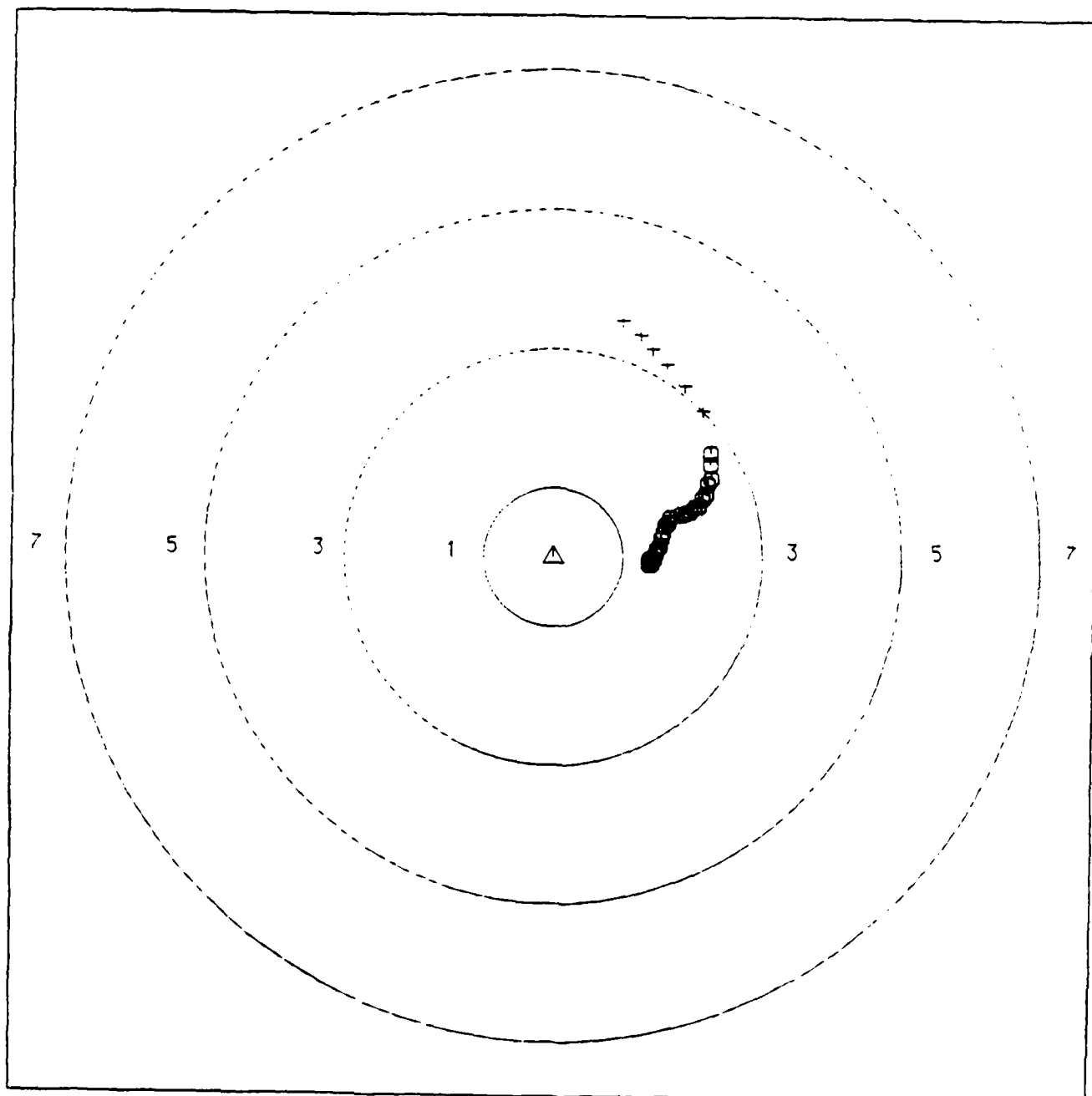


FIGURE D-61  
TCAS WARNING 41: BEARING PLOT

FLIGHT RA .....  
 MC SIM RA .....

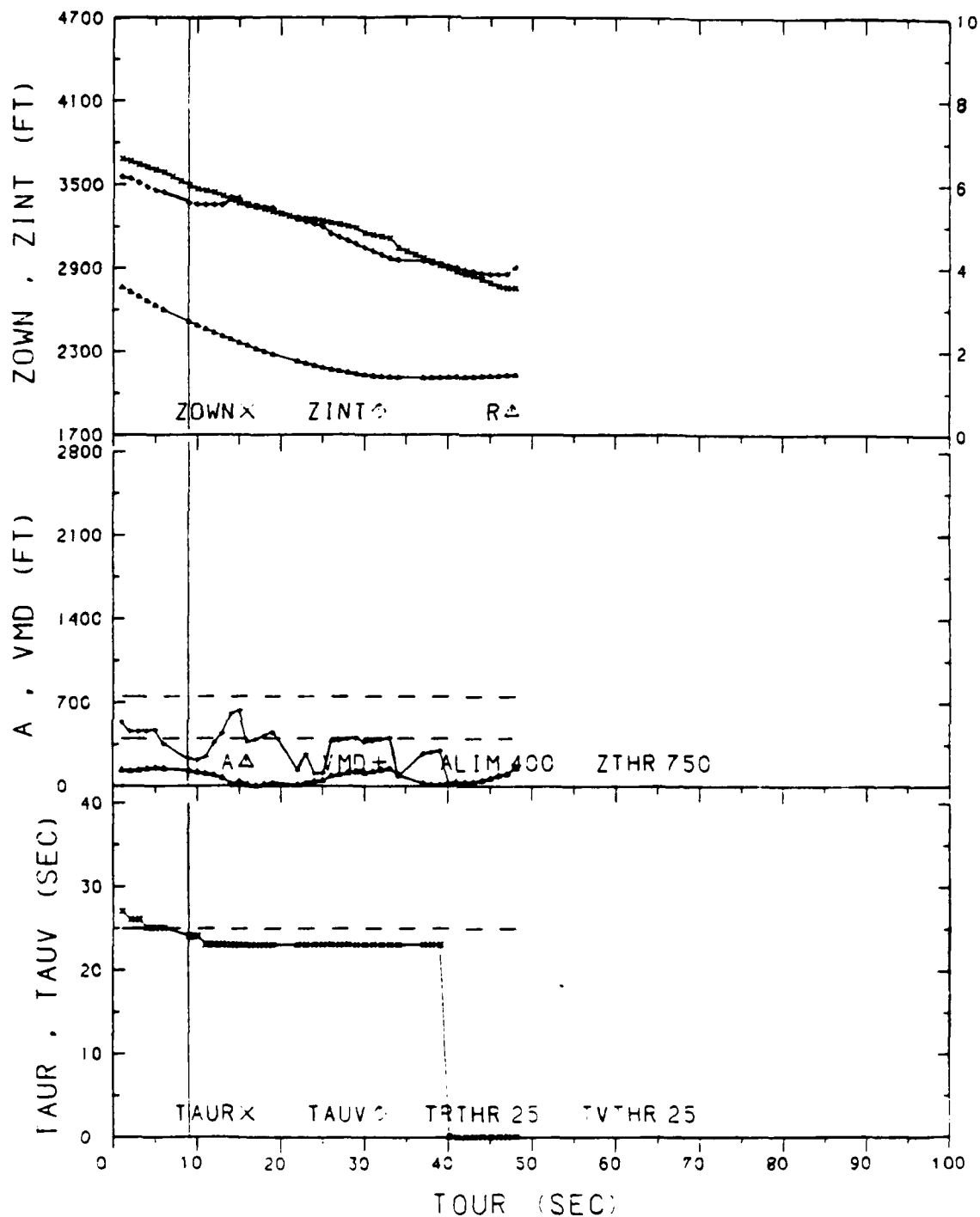


FIGURE D-62  
 TCAS WARNING 41: PARAMETERS



#### 42. TCAS WARNING 42

On October 6, 1987, aircraft 857N was on an 11 mile final into the Dallas-Ft. Worth airport, operating as Piedmont Flight 28. At 2248Z the aircraft was descending through 4,000 feet when a TCAS Caution advised the crew of traffic at 11 o'clock, 2 miles, and 2,000 feet above and descending. The crew visually acquired a B-727 which was on a final approach to the parallel runway (36R). As Flight 28 reached its assigned altitude of 3,000 feet, a TCAS Warning to DESCEND was issued, immediately followed by LIMIT VERTICAL RATE - DO NOT CLIMB. Since the pattern traffic was in sight and visual separation was being maintained, the crew elected to not respond to the Warning. Flight conditions at the time were day, VMC, with visibility greater than 13 miles.

The observer data for this encounter are shown in Figure D-63.

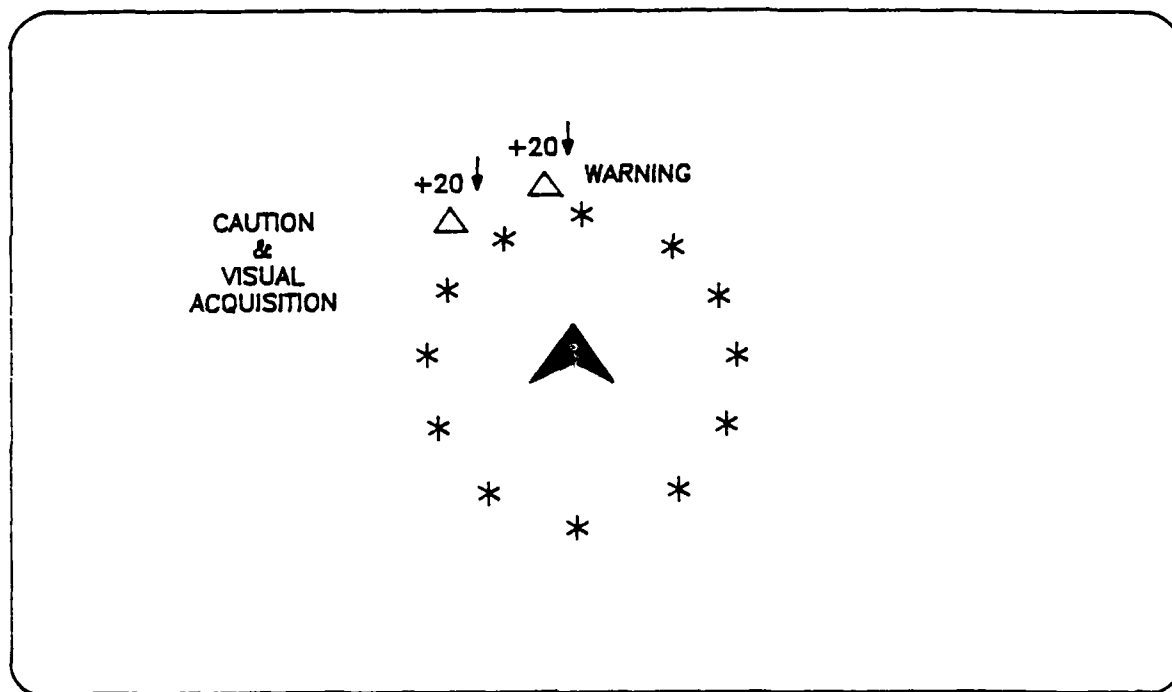
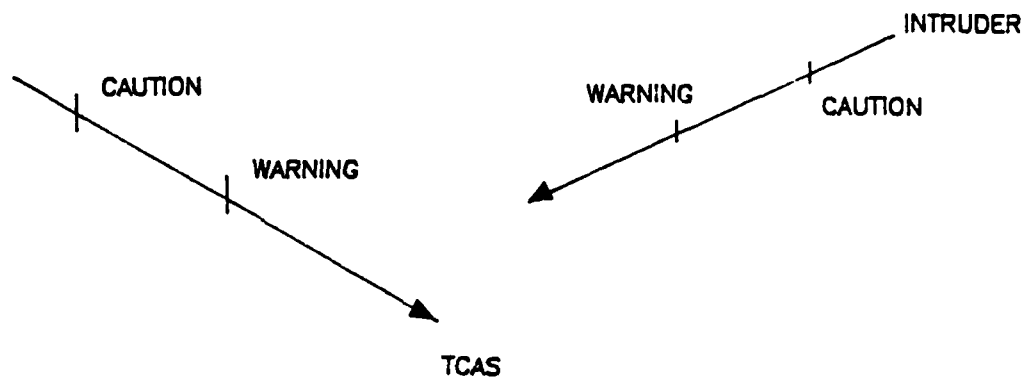


FIGURE D-63  
TCAS WARNING 42

#### 43. TCAS WARNING 43

On October 7, 1987, Piedmont Flight 32 was en route from Dayton, Ohio, to Dallas-Ft. Worth, Texas. The aircraft was level at 11,000 feet, inbound to the DFW terminal area on the BUJ (Blue Ridge) 220 degree radial at 37 DME. At 1434Z TCAS issued a Caution showing an intruder at 1 o'clock, 900 feet below and level, and outside of the CRT display range. Shortly after the Caution, ATC issued a traffic advisory to the crew and stated the intruder was on a reciprocal heading. When the traffic was approximately 4 miles away, the crew gained visual acquisition. At a range of 2 miles, TCAS issued a Warning to LIMIT VERTICAL RATE - DO NOT DESCEND. Since the TCAS aircraft was level at 11,000 feet, no action was required or taken by the pilot. The intruder passed along the right side of the TCAS aircraft and when the intruder reached the 5 o'clock position, the encounter ended. Flight conditions were day, VMC, with visibility 13 miles.

The observer data from this encounter are shown in Figure D-64.

11,000 → TCAS

← 10,000  
INTRUDER OR 10,100

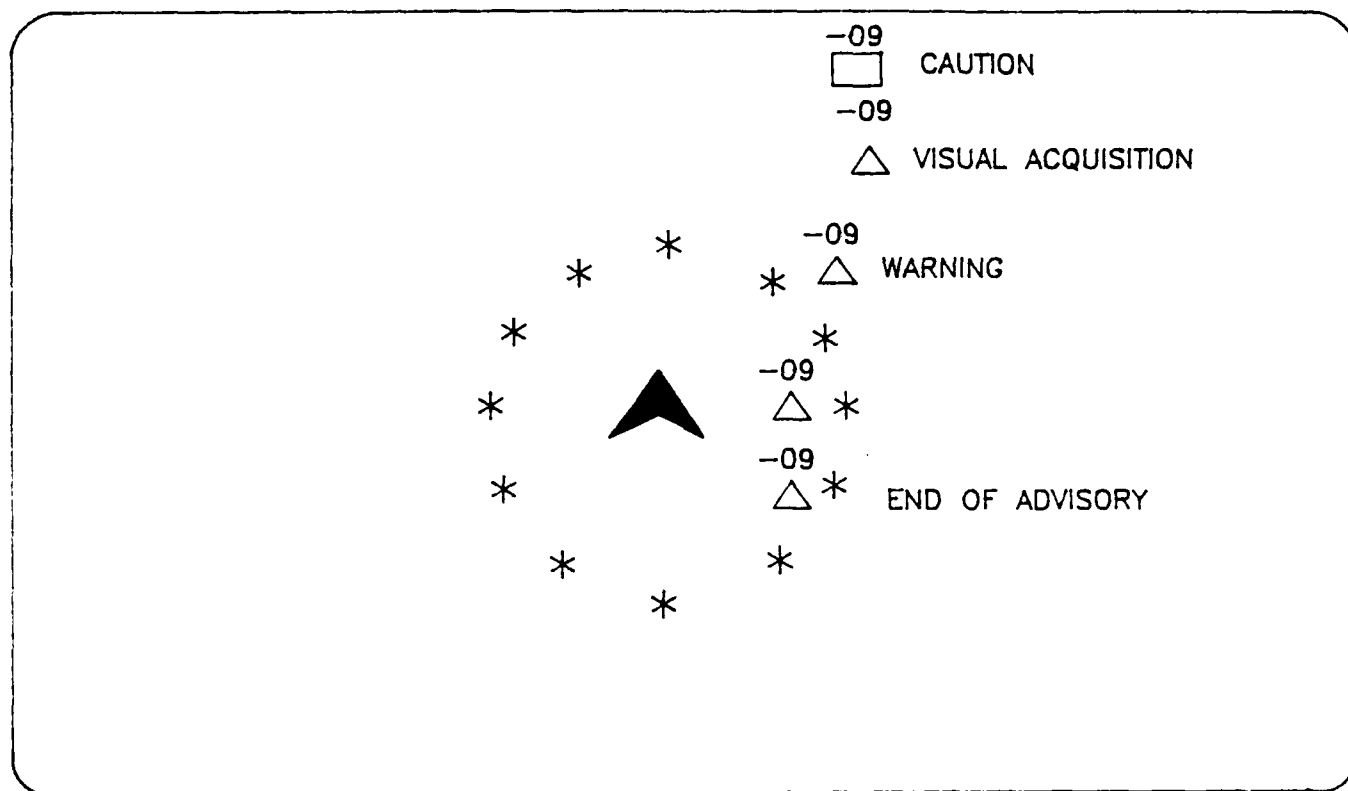


FIGURE D-64  
TCAS WARNING 43

#### 44. TCAS WARNING 44

On October 21, 1987, the TCAS aircraft was operating as Piedmont Flight 91 en route to Ft. Lauderdale, Florida from Baltimore, Maryland. At 2243Z the aircraft was established on a six mile final approach for landing on runway 9L at an altitude of 1800 feet. Flaps were set at 25 degrees, the landing gear was up, and the TCAS aircraft was descending at approximately 1000 fpm when TCAS issued a Caution showing traffic at 12 o'clock, 900 feet below and level, and at a range of 3 to 4 miles, and crossing the final approach course. Since Flight 91 was so near the runway and ATC had not issued any advisory, the crew questioned ATC (FLL Approach Control) about the traffic. The response was that the FLL tower was working the traffic and Flight 91 was told to contact the tower controller. As the crew switched to the tower frequency, TCAS generated a Warning to LIMIT VERTICAL RATE - DO NOT DESCEND GREATER THAN 500 fpm. The crew again asked ATC about the traffic and was assured by the tower that the intruder was under positive control. At the time of the Warning, the intruder's range had closed to within 1 to 1 1/2 miles horizontally and to 600 feet vertically. There was no visual contact established and the crew elected not to follow the Warning based on the ATC information. The intruder passed along the left side of the TCAS aircraft and when at the 9 o'clock position, the intruder was 300 feet below and at a range of less than 1 mile. The Warning ended with the intruder at 7 o'clock and co-altitude with Flight 91. Flight conditions at the time were day, VMC with visibility greater than 12 miles.

The observer data for this encounter are shown in Figure D-65.

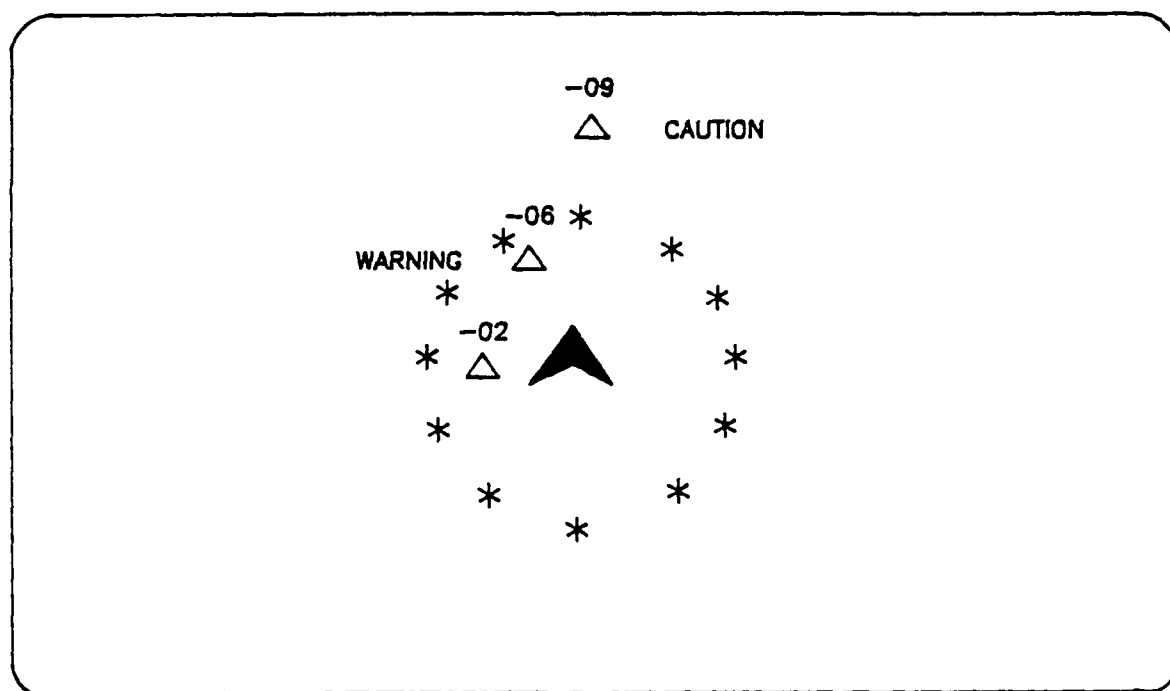
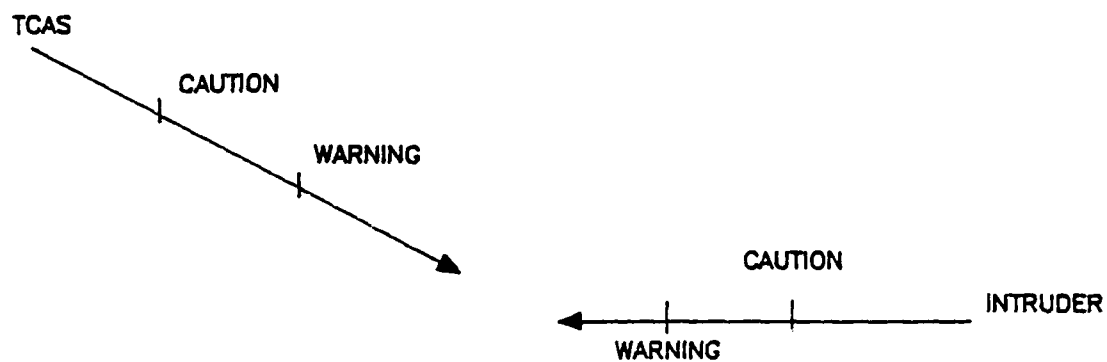


FIGURE D-65  
TCAS WARNING 44

#### 45. TCAS WARNING 45

On November 4, 1987, the TCAS aircraft was operating as Piedmont Flight 55 enroute from New York's LaGuardia airport to Richmond, Virginia. At 1740Z the TCAS aircraft was 38 DME northeast of Richmond and descending through 19,000 feet to an assigned altitude of 16,000 feet. ATC issued a traffic advisory for traffic at 12 o'clock, 12 miles, opposite direction, and level at 15,000 feet. The crew initiated a visual search for the traffic but was unable to visually acquire the intruder. At 1741Z, a TCAS Caution was issued against the same traffic. The Caution showed the intruder at the 11:30 position, beyond the display range of the CRT, and at a relative altitude of minus 1,500 feet. The crew visually acquired the intruder following the Caution and continued their descent at 2,000 fpm. When the range between the intruder and TCAS aircraft reached 2 nm and when the relative altitude showed minus 900 feet, a LIMIT VERTICAL RATE -- DO NOT DESCEND GREATER THAN 1,000 FPM Warning was issued. The crew reduced the TCAS aircraft's descent rate from 2,000 fpm to 1,000 fpm. As the intruder passed the 9 o'clock position, the Warning was removed. Flight conditions were day, VMC, with visibility of 7 miles.

The observer data for this encounter are shown in Figure D-66.





#### 46. TCAS WARNING 46

On November 13, 1987, the TCAS aircraft was operating as Piedmont Flight 591 from New York, New York, to Baltimore, Maryland. At 1313Z, the TCAS aircraft was established on a 7 mile final to runway 33L at BWI and was initiating a descent from 3,500 feet. A TCAS Caution was issued showing an intruder aircraft at 10 o'clock, 3 miles, and at a relative altitude of plus 400 feet. The crew initiated a search for the traffic and visually acquired the intruder at a range of approximately 2 miles. The intruder continued to track towards the TCAS aircraft and at a range of approximately 1 mile a DESCEND Warning was issued. The flight crew increased their descent rate to 1,000 fpm and maintained that rate until the Warning was removed. The Warning was removed with the intruder's range less than a half mile and with 700 feet of vertical separation. Flight conditions were day, VMC, with visibility reported at 7 miles.

The observer data for this encounter are shown in Figure D-67.

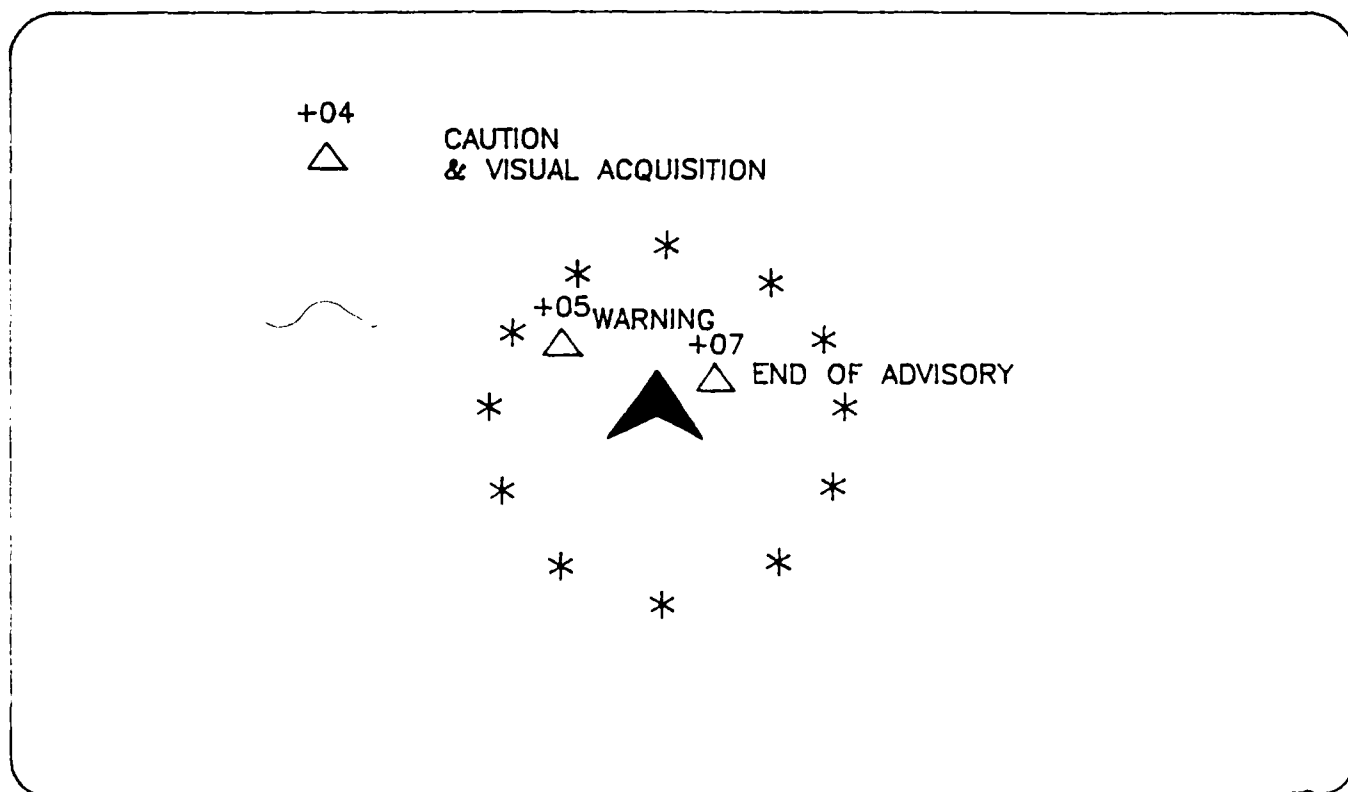
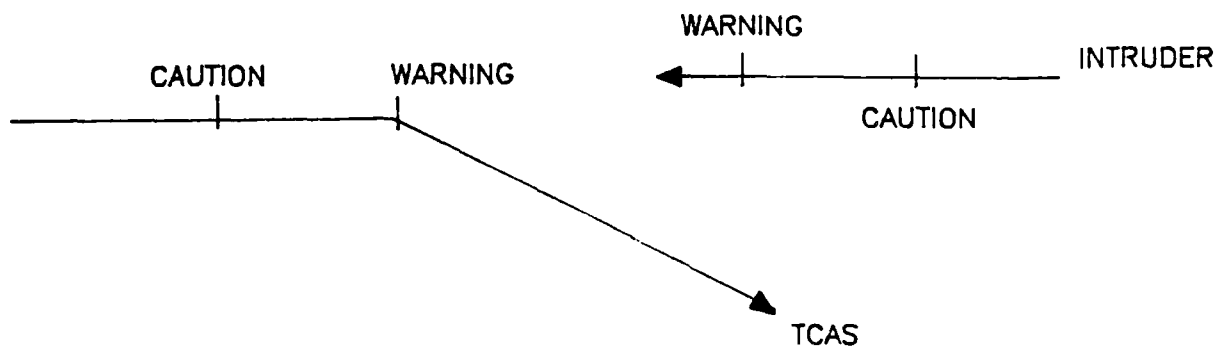


FIGURE D-67  
TCAS WARNING 46

#### 47. TCAS WARNING 47

On November 16, 1987, the TCAS aircraft was operating as Piedmont Flight 87 from Jacksonville, Florida, to Miami, Florida. After departure, Flight 87 climbed to an intermediate altitude of 11,000 feet. While level at 11,000 feet, TCAS issued a Caution against an intruder aircraft at 11 o'clock, 7 miles, and 500 feet above the TCAS aircraft. The recorded data shows a second intruder at 11 to 12 o'clock and 3 miles which was not equipped with an encoding altimeter. The crew called ATC to verify the location of the traffic shown at 11,500 feet and ATC confirmed the traffic's location but noted they were not in contact with the aircraft. The crew visually acquired the traffic while talking with ATC. However, ATC did not mention the non-Mode C traffic. Shortly after the conversation with ATC, Flight 87 was cleared to climb and maintain 13,000. As the climb was initiated, a Warning was issued to DO NOT CLIMB and the TCAS aircraft's climb rate was reduced. After nine seconds, the Warning was strengthened to DESCEND. Since the intruder was in sight and the crew saw that they would pass safely, the climb to 13,000 feet was continued. At CPA, the intruder's horizontal range was approximately two miles and the vertical separation was approximately 300 feet. The information shown on the recorded data was consistent with the ATC data on the encounter.

The recorded data for this encounter are shown in Figures D-67 and D-68.

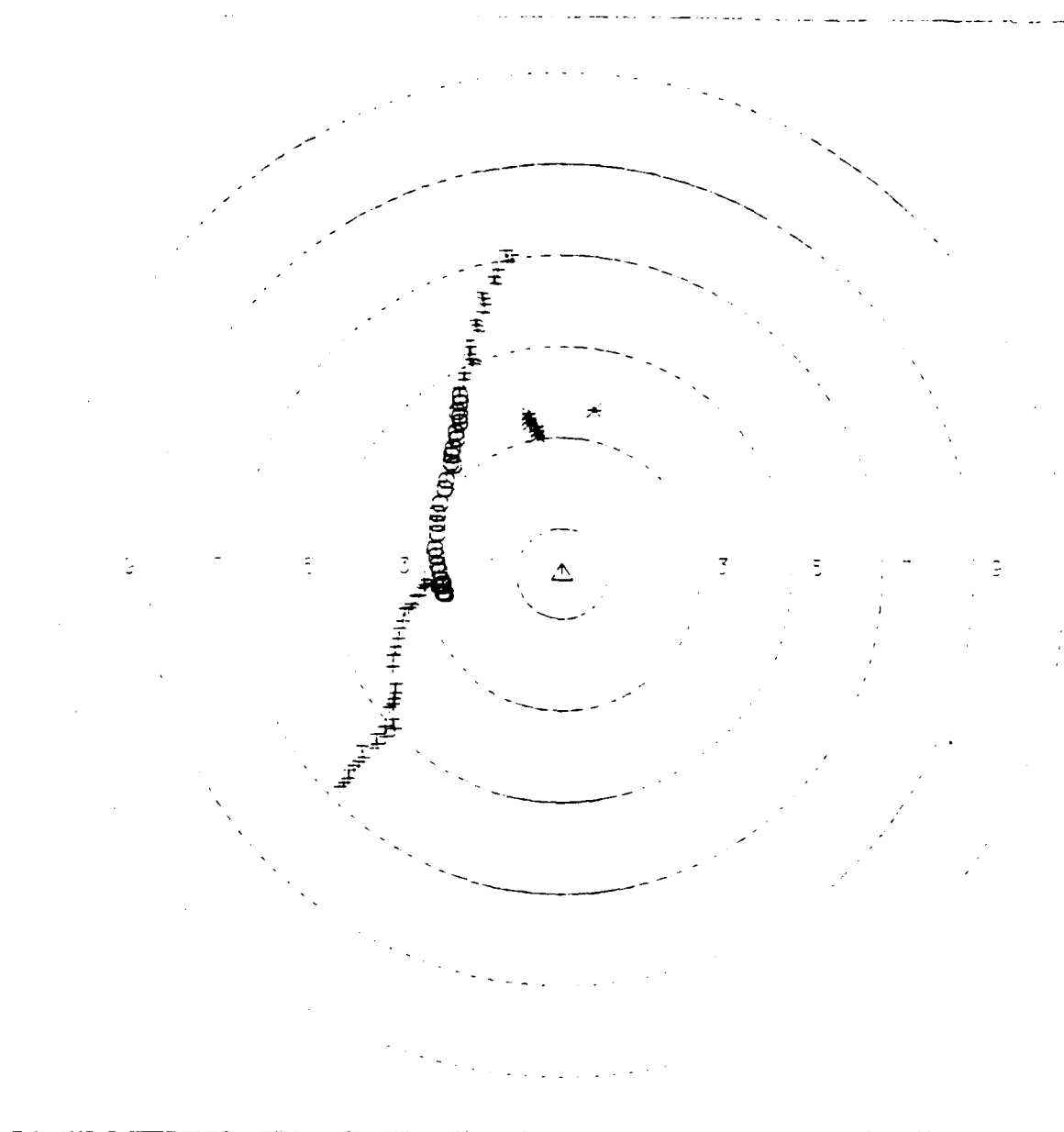


FIGURE D-67  
TCAS WARNING 47: BEARING PLOT

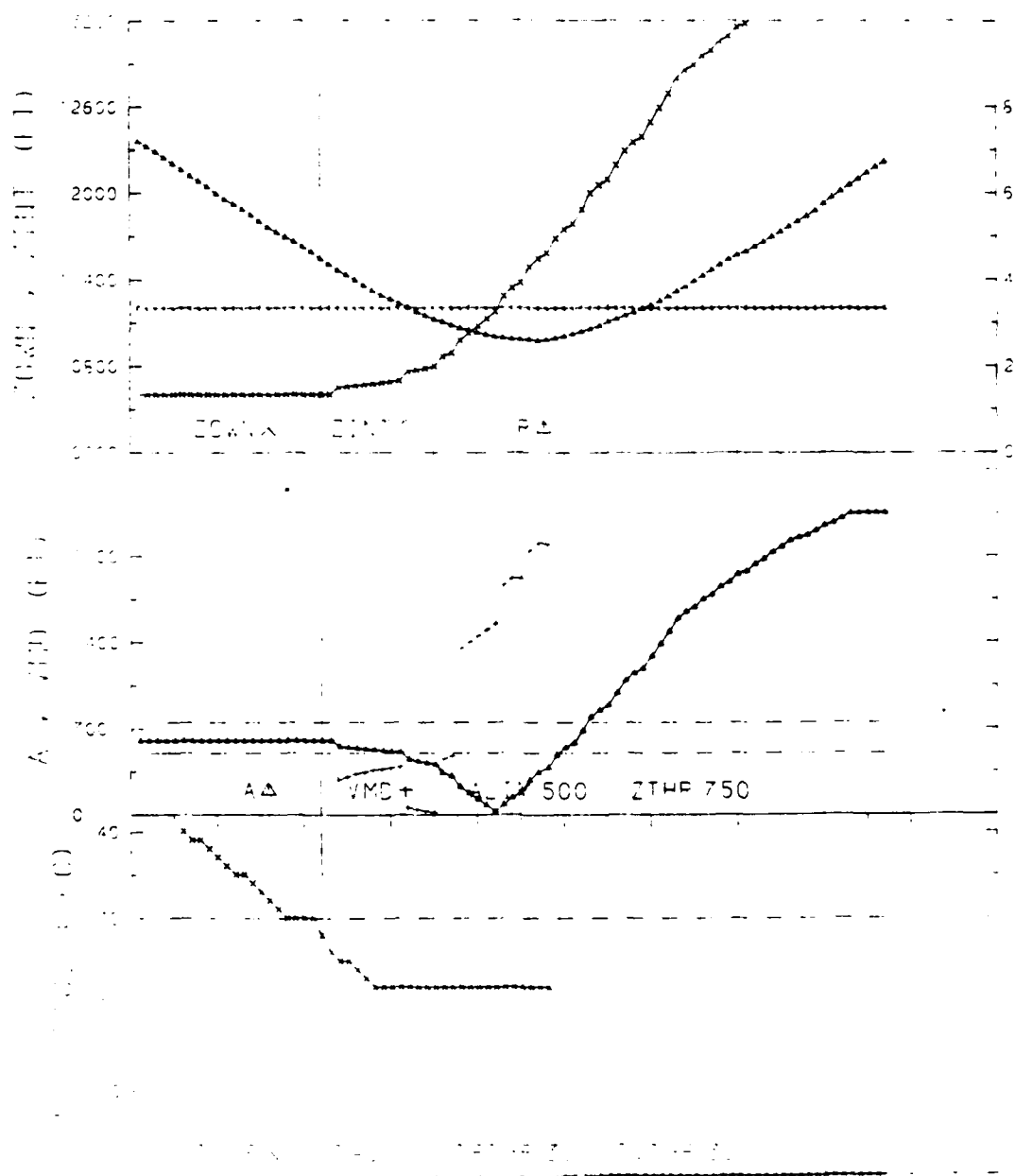


FIGURE D-68  
TCAS WARNING 47: PARAMETERS

#### 48. TCAS WARNING 48

On January 19, 1988, Piedmont Flight 77 was en route from Tampa, Florida, to the Baltimore-Washington International Airport. As Flight 77 was approaching BWI, a Caution was issued against an intruder at 11 o'clock, 4 miles, and 3,500 feet. The Caution occurred while Flight 77 was 12 miles south of the airport, level at 4,000 feet, and after an ATC traffic advisory had been issued. The crew visually acquired the traffic when the Caution was issued and watched it pass along the left side of the TCAS aircraft. When the intruder reached the TCAS aircraft's 9 o'clock position, a Warning was issued to CLIMB. Since the intruder and TCAS aircraft were diverging in range, Flight 77 remained level at 4,000 feet. No recorded data are available for this encounter so its is difficult to determine what caused the Warning to be issued. Flight conditions were night, VMC, with visibility reported at 10 miles.

The observer data on this encounter are shown in Figure D-69.

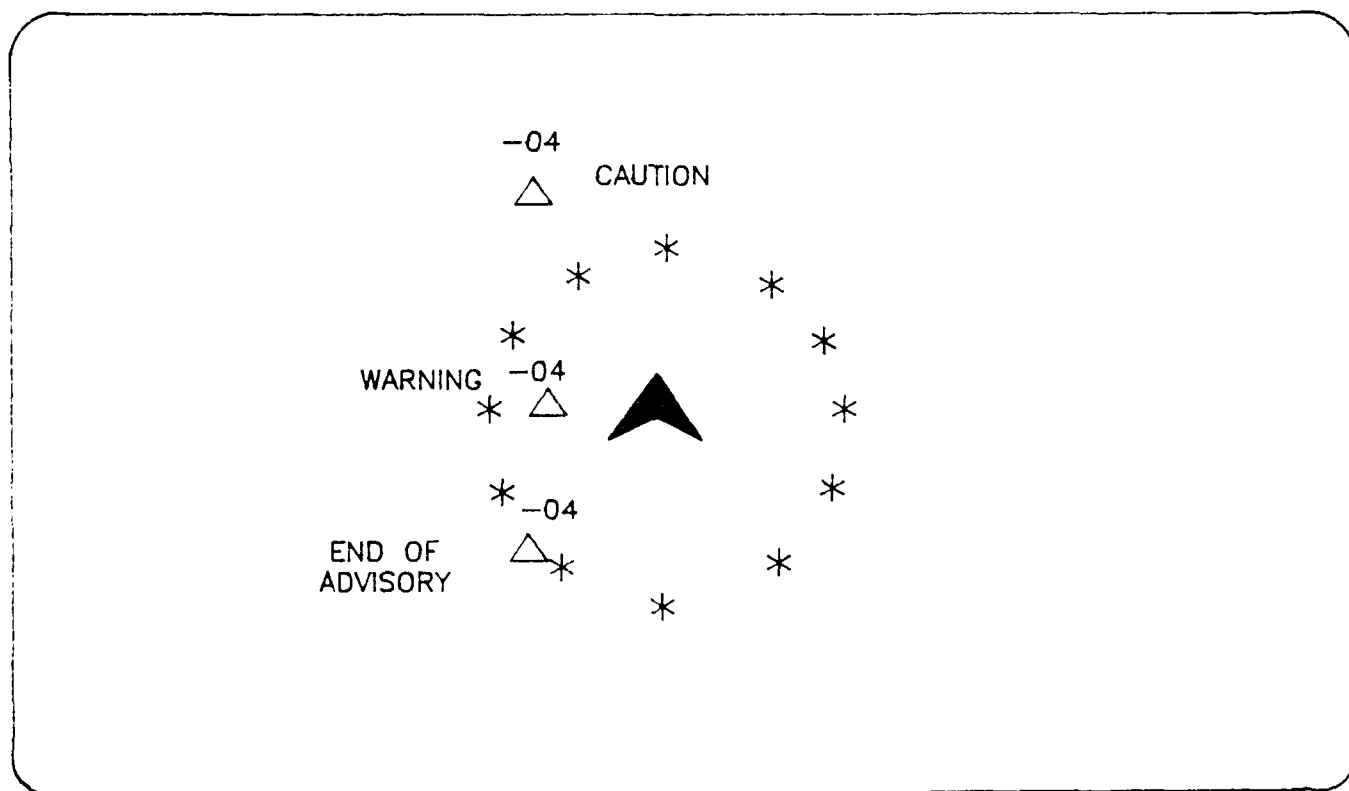
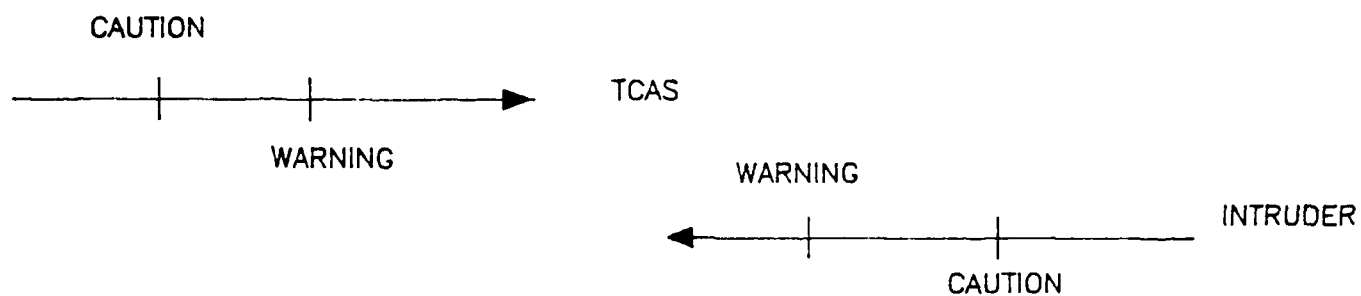


FIGURE D-69  
TCAS WARNING 48

## APPENDIX E

### EQUIPMENT MAINTENANCE ACTIVITIES

ARINC Research Corporation was tasked to provide maintenance for the TCAS avionics and data recording equipment during the Phase II evaluation. As a result, a contract was established between ARINC Research and the Dalmo Victor Division of Singer to provide a mechanism for repairing equipment failures or modifying the design of the avionics. The support provided by Dalmo Victor in handling the avionics maintenance activities was excellent throughout the evaluation.

#### 1. SYSTEM SELF-TEST

The TCAS avionics contain an extensive built-in test system that performs seven different internal tests. Six of the tests are performed continuously when the TCAS system is operating in its normal mode. When it is manually placed in self-test, five of the six continuous tests plus the seventh test are performed (the transmitter power test is omitted). In addition, all spoken audio advisories, control panel lights, and IVSI lights are sequenced in a predetermined manner. The SELF-TEST switch is spring-loaded so that it cannot be left in the self-test mode. The self-test feature worked well during the evaluation. No hardware or software problems reported during the evaluation that were not detected by the self-test.

##### 1.1 Manual Self-Test

Manual Self-Test is initiated by momentarily putting the control panel switch in the SELF-TEST position and then releasing it. The red fail light on the control panel blinks on and off. The lights on the IVSI are illuminated in the following order:

- The upper eyebrows
- The lower eyebrows
- The climb arrow
- The descend arrow
- The climb and descend arrows flash
- The fail lamp

An audio test accompanies the sequence of the IVSI lights. The following words are heard:



- Limit Vertical Rate
- Limit Vertical Rate
- Climb
- Descend
- TCAS Invalid

At this point, the system performs six internal tests to determine the state of the TCAS hardware and software. At the end of a successful self-test, the fail light on the control panel and the IVSI are turned off and the weather radar presents the following displays:

- The own-aircraft symbol is displayed at the normal position with the 12 clock position symbols shown at 2 miles in range.
- The software version number and the word PASS are displayed in the upper left corner under the range and altitude headings.

The system then reverts to the AUTO mode, and the indicator returns to the weather radar display unless a Caution or Warning is present.

If self-test fails, the fail lights on the control panel and IVSIs remain illuminated. The weather radar display shows the words CAS FAIL and a number indicating the test that failed. The weather radar indicator then returns to the weather radar display, and the fail lamps continue to show the CAS FAIL indication.

When a failure is detected, the operation of TCAS is inhibited.

The tests that are performed during a self-test, with the failure number for each test, are as follows:

- The transmitter power test is performed only in the continuous-monitor self-test when the system is in STANDBY or AUTO. Although the transmitter is not operated with the aircraft on the ground, it remembers the last transmitter test performed before going into manual self-test. (Test 1)
- Each DF port is individually excited in the antenna, and the proper angle is read out by the computer. A failure indication here shows a bad antenna, antenna cable, swapped antenna cables, bad receivers, bad video, or bad A/D converters in the processor. (Test 2)
- The CPU continuously sums the contents of all the program memory contents and read and write checks the RAMS. If the final sum is incorrect, or the RAM locations cannot be written into and read from the failure indication is given. (Test 3)
- The ATRBS video test indicates a failure to properly degarble and read ATRBS replies. (Test 4)

- The Mode S video test indicates a Mode S decoder error. (Test 5)
- The pressure altimeter code has an invalid code ("C" bits form an illegal code). (Test 6)
- The radio altimeter status flag indicates that the radio altimeter is bad. (Test 7)

If a power test is failed, FAIL 1 is displayed. If the transmitter has failed, the failure is detected when the weight is removed from the wheels at takeoff. The fail light on the control panel immediately illuminates, indicating that the TCAS is not operating.

The manual self-test was typically performed before the first flight of the test aircraft each day and whenever a new crew began to use the system during the day.

## 1.2 Continuous Performance Monitor

While in STANDBY or AUTO, TCAS continuously performs a series of six self-test functions. These functions are performed during the idle time between TCAS functions. They are normally completed in 3 seconds.

The memory RAM/ROM test (see Section 1.1) takes too long and is not performed in this mode. The transmit power test is continuous. Both a maximum power test and a minimum power test are performed to verify that the rated power is available and that the whisper-shout attenuator can reduce the transmitter power for the whisper-shout sequence. A failure causes a failure light to appear. A CAS FAIL indication appears on the weather radar display if the TCAS TRACKS mode is selected. The failure is remembered and, if manual self-test is operated, the FAIL 1 appears.

Any failure that is detected illuminates the FAIL indication on the TCAS control panel and the IVSIs. TCAS is automatically configured to discontinue tracking, and Cautions or Warnings cannot be displayed on the IVSIs or radar display.

If the TCAS/TRACK switch is momentarily activated, the weather radar shows a normal display with no tracks and with CAS FAIL written under the range and altitude legend.

If a manual self-test is initiated, the normal self-test is performed, and at the end of the test the failure number is displayed on the weather radar display.

In the event of a failure, there is no immediate hazard to the aircraft. The TCAS fails passive, interrogations are stopped, and no advisories are given.

## 2. DATA TAPE ANALYSIS

The data tapes were periodically removed from the test aircraft and forwarded to MITRE, the FAA Technical Center, and MIT Lincoln Laboratory for detailed analysis. The analyses identified three problems before the beginning of the Phase II data collection effort in March 1987. These problems occurred in 1986 and early 1987 while the avionics were being operated in STANDBY to verify the equipment's performance while the crew training program was being validated.

The three performance problems detected by data tape analysis included one hardware and two software problems. All were detected prior to the first operational flight. The first software problem involved issuing Cautions against non-Mode C traffic on coasted, or carried over, track information. The surveillance tracker would continue to track the intruder, but the CAS tracker would drop it. When CAS picked up the track again, it assumed that the intruder was a new target and had no range rate. When the next report from the surveillance was a coast, the range was set to a default value of 32 miles. When a valid range report was received (typically for a range much less than 32 miles), the intruder appeared to have a high range rate, which satisfied the Caution criteria. The use of coast data for Cautions is inhibited for Mode C tracks but not for non-Mode C tracks. No software changes were made to the avionics, and this anomaly may account for the higher than expected incidence of short non-Mode C Cautions observed during this evaluation.

The second software problem involved issuing a Warning on an intruder 2,400 feet below the TCAS aircraft; the intruder was apparently on the ground. Analysis of the recorded tape data showed an invalid value for a variable used to set altitude thresholds. This invalid value appeared to be a result of turning TCAS on before having stable altitude data from the Air Data Computer and Radar Altimeter inputs. Two possible solutions to the problem included procedurally cycling TCAS prior to takeoff to verify that its variables were initialized with valid altitude data, and changing the default initialization values in software so that power-up sequences would not matter. The software change was implemented to minimize the impact on crew procedures. The software modification was completed in January 1987 and was approved for flight by the Atlanta ACO.

The hardware problem detected by data tape analysis involved a loss of time-of-day data from the real-time clock. Sometimes data tapes were returned with the correct time-of-day, and sometimes the time would be all zeroes. In June 1986, troubleshooting was performed on the aircraft's time-of-day clock installation. No fault was ever found with the aircraft wiring, the clock, or the recorder. The problem persisted throughout the evaluation despite repeated efforts to diagnose it.

## 3. HARDWARE ANALYSIS

Hardware anomalies that occurred prior to and during the Phase II evaluation included a hard FAIL2 (failed antennas, cables, receivers,

video, or processor A/D), intermittent FAIL2, hard FAIL4 (ATCRBS degarbler failure), hard FAIL5 (Mode-S decoder and other receiver failure), hard FAIL3 (PROM checksum failure), incorrect aural annunciations during self-test, inoperative IVSI lights during self-test, and the dropout of time-of-day information. A chronological summary of these anomalies and the associated corrective actions is provided in the following paragraphs.

The FAIL2 indication and the FAIL4 indications that occurred in May 1986 were the result of failed RF receivers in the BEU and an unseated circuit card in the processor. These faults occurred prior to the first operational flight. Both the BEU and the processor were returned to Dalmo Victor for repair. Fault conditions discovered at Dalmo Victor included damaged ICs, damaged PC traces, damaged plated-through holes, and damaged card edge connectors. Each of the faults was repaired, the equipment was tested, and the units were returned to service.

When the FAIL4 recurred in June 1986, ARINC and Piedmont personnel removed the processor, reseated the errant circuit card (the same one that had caused the FAIL4 in May), closed the processor, and reinstalled it on the test aircraft. Self-test was passed several times in succession, and the system was returned to operational status.

In May 1987, just after flight operations began, the self-test annunciations repeated the word "zero" instead of the appropriate Warning commands. The CRT remained blank, but F3 (equivalent to FAIL3) was indicated on the CDU in the E&E bay. The processor was returned to Dalmo Victor for analysis and repair, and a damaged PROM IC was discovered. New PROMs were programmed, a detailed bench test was performed, and the aircraft installation was ground-tested to verify proper repair of the avionics. Following the ground check at Piedmont, the avionics were returned to service.

In June 1987 the IVSI lights did not illuminate during a self-test, and self-test would not run to completion. The entire system was removed and returned to Dalmo Victor for repair. The CDU, which provides drives to the IVSI lights, had a failed transistor that inhibited all IVSI displays. The processor had a failed RAM IC and a damaged card edge connector. During retest, the CDU failed again. Card guides on the CDU chassis were found to have become detached from the chassis. The card guides were repaired and the units returned to service. The repair activity was followed by a complete ground test of the avionics on the test aircraft. Following successful completion of this test, the equipment was returned to operational status and the Phase II evaluation continued.

In August 1987, self-test indicated a FAIL5. The processor was returned to Dalmo Victor for repair, and a damaged IC was discovered. The unit was subsequently repaired, retested, and returned to Piedmont. After the processor was installed on the test aircraft, a successful completion of self-test verified that the system was operational.

In September 1987, the FAIL2 indication occurred for a second time. Replacing the BEU did not resolve the failure, so the processor was removed and returned to Dalmo Victor for repair. Fault conditions discovered at the repair facility included broken traces on a circuit card, damaged IC leads, and eroded plated-through holes. The damage was repaired and the unit returned to service. Again, a successful self-test verified proper system operation in the test aircraft.

Throughout the summer of 1987, an intermittent FAIL annunciation was alternately displayed and cleared on the IVSI. A self-test would display FAIL2 on the CRT. The fail indications occurred only on the ground from midday to dusk when the outside air temperature was in the upper 80s or higher. Once the test aircraft was airborne, the failure indications would clear and the system would perform correctly. Any attempts to troubleshoot and isolate the problem were necessarily performed at night in lower temperatures. The problem would not repeat itself during these nighttime troubleshooting sessions. Similarly, the problem could not be duplicated at the vendor's repair facility. An operational procedure was developed to turn the equipment OFF while the test aircraft was on the ground and turn it back ON when the test aircraft was number one for takeoff. The problem eventually stopped occurring when cool weather returned in September.

#### 4. SUMMARY

None of the hardware anomalies were caused by a flaw in the system's design. Most of the problems outlined above occurred on a single circuit card assembly. These problems appear to be related to age and fatigue, since the equipment was not designed according to normal avionics design practices and standards. The equipment has been used in both the Phase I and Phase II evaluations, so some deterioration is expected.

The software anomaly related to the incorrect parameter used in setting the sensitivity levels resulted in a change to the MOPS. The other software anomaly is related to the short duration Cautions and is currently under review by MITRE.

## APPENDIX F

### REFERENCES

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